

Argonne National Laboratory

THE SOLUBILITY OF METALS IN LIQUID ZINC

by

Irving Johnson and Ira G. Dillon

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ANL-7083
Chemical Separations
Processes for Plutonium
and Uranium (TID-4500)
AEC Research and
Development Report

ARGONNE NATIONAL LABORATORY

9700 South Cass Avenue
Argonne, Illinois 60439

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Irving Johnson and Ira G. Dillon

Chemical Engineering Division

November 1965

Operated by The University of Chicago
under
Contract W-31-109-eng-38
with the
U. S. Atomic Energy Commission

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INTRODUCTION

Solubility data for metals in zinc or other solvents are useful a) for process development, b) for corrosion studies, and c) for theoretical studies of liquid-metal solutions. In particular, reactor-fuel decontamination processes employing liquid zinc as a solvent are being developed in the Chemical Engineering Division. Therefore, there is considerable interest in the solubility of many metals in liquid zinc. The alloy systems covered are listed in Table I.

TABLE I. Index of Alloy Systems
(Alphabetically according to chemical symbol)

Element Symbol	Element Name	System Type	Page No.
Ag	Silver	Intermetallic phases	17
Al	Aluminum	Simple eutectic, solid solutions	19
As	Arsenic	Intermetallic phases	21
Au	Gold	Intermetallic phases	23
Ba	Barium	Intermetallic phases	25
Be	Beryllium	Unknown	27
Bi	Bismuth	Two immiscible liquid layers	29
Ca	Calcium	Intermetallic phases	31
Cd	Cadmium	Simple eutectic	33
Ce	Cerium	Intermetallic phases	35
Co	Cobalt	Intermetallic phases	37
Cr	Chromium	Intermetallic phases	39
Cu	Copper	Intermetallic phases	41
Fe	Iron	Intermetallic phases	43
Ga	Gallium	Simple eutectic	46
Ge	Germanium	Simple eutectic	48
In	Indium	Simple eutectic	50
La	Lanthanum	Intermetallic phases	52
Li	Lithium	Intermetallic phases	55
Mg	Magnesium	Intermetallic phases	57
Mn	Manganese	Intermetallic phases	59
Mo	Molybdenum	Intermetallic phases	62
Na	Sodium	Intermetallic phases	64
Nb	Niobium	Intermetallic phases	66
Nd	Neodymium	Intermetallic phases	68
Ni	Nickel	Intermetallic phases	70
Pb	Lead	Two immiscible liquid layers	72
Pd	Palladium	Intermetallic phases	74
Pr	Praseodymium	Intermetallic phases	76
Pt	Platinum	Intermetallic phases	78
Pu	Plutonium	Intermetallic phases	80
Rh	Rhodium	Intermetallic phases	82
Ru	Ruthenium	Intermetallic phases	84
Sb	Antimony	Intermetallic phases	86
Si	Silicon	No intermetallic phases	88
Sn	Tin	Simple eutectic	90
Sr	Strontium	Intermetallic phases	91
Tc	Technetium	Intermetallic phases	93
Th	Thorium	Intermetallic phases	95
Ti	Titanium	Intermetallic phases	97
U	Uranium	Intermetallic phases	99
V	Vanadium	Intermetallic phases	102
Y	Yttrium	Intermetallic phases	105
Zr	Zirconium	Intermetallic phases	107

The solubility of a number of metals in liquid zinc was reviewed by M. W. Nathans in 1957, Ref. 100.* This report brings the review up to July 1965 and includes much unpublished data from Argonne National Laboratory; also, all original papers used as sources were examined. Nuclear Science Abstracts and Chemical Abstracts were searched through July 1965. This report covers binary systems only.

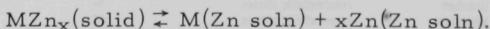
Hansen and Anderko's book⁵⁰ was used extensively as a source of phase diagrams and solubility data. The first supplement by P. Elliot³⁹ appeared just before this report was issued, significant changes were incorporated into this report. The report by Stanton *et al.*¹³⁹ was used extensively for crystal-structure data. The bibliography at the end of this report lists sources of system data.

SOLUBILITY

The low melting point of zinc, relative to the majority of metals, and its marked propensity to form stable intermediate phases with other metals permit the conventional chemists' definition to be used for solubilities of metals in liquid zinc. The solubility of a metallic solute in liquid zinc is therefore defined as the weight or atom percent of the solute in the liquid-zinc-rich phase in equilibrium with a solid phase, which may be either the pure solute metal or a solute metal-zinc intermediate phase. In a few cases, such as when two partially immiscible liquid phases or a simple eutectic system is formed, appropriate deviations from this definition will be made. Generally, the solubility data reported refer only to the zinc-rich parts of the phase diagram. For most applications of solubility data, it is advantageous to have knowledge of the phase diagram of the systems and the composition of the equilibrium solid phase. We have briefly summarized the available phase information for each system; however, we have reported solubility data even when uncertainties exist as to the equilibrium solid phase.

The solubility data are presented in three different forms. First, the data are presented in tabular form; both the original data and smoothed data are given. Second, graphs of original data are presented with a least-squares line drawn through the points. Third, equations for the solubility as a function of temperature (based on the least-squares line) are presented.

The functional relation between the solubility and temperature may be deduced as follows. The solubility equilibrium may be represented by the equation



*References are listed in alphabetical order at the end of this report.

Therefore

$$RT \ln a_M + xRT \ln a_{Zn} - \Delta G_f^\circ_{MZn_x} = 0,$$

where a_M and a_{Zn} are the activities of the solute metal and zinc in the liquid phase, respectively, and $\Delta G_f^\circ_{MZn_x}$ is the standard free energy of formation of the intermediate phase at the temperature T . Rearranging, one obtains

$$\log x_M = \frac{\Delta G_f^\circ_{MZn_x}}{2.3RT} - \log \gamma_M - x \log a_{Zn},$$

where x_M and γ_M are the atom fraction and the activity coefficient of M in the liquid zinc phase, respectively. When x_M is small, $a_{Zn} \approx 1$ and the equation may be written

$$\log x_M \approx \frac{\Delta G_f^\circ_{MZn_x} - \bar{G}_M^{xs}}{2.3RT},$$

where \bar{G}_M^{xs} is the excess free energy of M in the solution. Replacing the free-energy functions by their equivalent enthalpy and entropy functions, one obtains

$$\log x_M = \frac{(\Delta H_f^\circ_{MZn_x} - \bar{L}_M)}{2.3RT} + \frac{(\Delta S_f^\circ_{MZn_x} - \bar{S}_M^{xs})}{2.3R}.$$

Since the enthalpies and entropies are usually slowly-varying functions of temperature (when the composition of the solid phase does not vary), one expects a linear relation between the logarithm of the solubility and the reciprocal of the absolute temperature. The slope will be proportional to the difference between the enthalpy of formation of the compound and the relative partial molar enthalpy of M in the solution. Thus, when the composition of the solid phase changes abruptly, as when the equilibrium solid phase changes from one compound to another, the slope also changes sharply. Precise solubility measurements may therefore be used to obtain evidence for changes in the composition of the equilibrium solid phase that occur at an incongruent melting point on a phase diagram.

Empirically one finds that a plot of the logarithm of the solubility vs the reciprocal of the absolute temperature is linear for many systems. This functional relation therefore affords a convenient method for interpolation and limited extrapolations of solubility data. Care must be exercised when extrapolating, since a particular equation is valid only for a given equilibrium solid phase, which in practical cases will correspond to a given temperature range.

Most of the older solubility data were obtained by thermal analysis. Such data are of limited accuracy, particularly at lower temperatures where the solubility is often very low in liquid zinc. Solubilities below a few atom percent are best determined by analysis of the equilibrium liquid phase. Typically, this latter method yields solubilities with precision in the $\pm 5\%$ range.

SILVER-ZINC

A. Phase Information1. Phase Diagram

The phase diagram for the silver-zinc system is reported in Hansen and Anderko⁵⁰ (p. 63). A complex series of intermediate phases with wide composition ranges is shown.

2. Intermetallic Phases

The structures of silver-zinc intermetallic phases given by Stanton *et al.* (p. 6) in their review are:¹³⁹

Compound	Crystal Class	Lattice Parameters, Å	References
AgZn ₃ * (ϵ -phase)	Hexagonal	a = 2.82 c = 4.42	6, 111
Ag ₅ Zn ₈ * (γ)	Cubic	a = 9.32-9.35	6, 88, 111
AgZn* (β)	Cubic	a = 3.156	6, 35, 46, 137
AgZn* (ζ)	Hexagonal	a = 7.636 c = 2.820	6, 14, 113

*Approximate composition, not line compounds.

B. Solubility Data

Andrews *et al.*⁶ and Heycock and Neville⁶¹ measured the solubility of silver in liquid zinc in the zinc-rich range by thermal analysis. These measurements cover the range of 419 to 661°C, and the data are shown in Fig. 1. Several phases are in equilibrium with the liquid phase

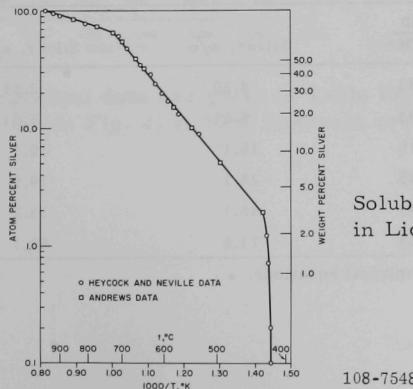


Fig. 1
Solubility of Silver
in Liquid Zinc

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(ϵ from 430 to 630°C, γ from 630 to 665°C, β from 665 to 710°C, and α from 710 to 960°C). The direct measurements may be approximately represented by the following empirical equations over the range of 440 to 710°C:

$$\log (\text{a/o Ag}) = 5.543 - 3714T^{-1};$$

$$\log (\text{w/o Ag}) = 5.422 - 3470T^{-1}.$$

Experimental data are given in Table II, and calculated values of the solubility at 50°C intervals are given in Table III.

TABLE II. Solubility of Silver in Liquid Zinc: Experimental Data

t, °C	$\frac{1000}{T, ^\circ\text{K}}$	Silver, w/o	Silver, a/o	t, °C	$\frac{1000}{T, ^\circ\text{K}}$	Silver, w/o	Silver, a/o
959 ^a	0.812	100.0	100.0	620 ^a	1.120	34.1	23.9
927 ^a	0.833	97.0	95.2	606 ^a	1.138	28.9	19.8
901 ^a	0.852	94.7	91.5	592 ^a	1.156	25.2	17.0
850 ^b	0.890	89.9	84.4	580 ^b	1.172	22.5	15.0
809 ^a	0.924	85.5	78.1	571 ^a	1.185	19.8	13.0
773 ^b	0.956	82.3	73.7	545 ^b	1.222	15.5	10.0
725 ^b	1.002	75.5	65.2	538 ^a	1.243	13.8	8.83
711 ^a	1.016	71.8	60.7	495 ^b	1.302	8.00	5.00
701 ^b	1.027	66.5	54.5	430.7 ^b	1.421	3.10	1.90
688 ^a	1.040	59.7	47.3	425.2 ^a	1.433	1.95	1.19
666 ^b	1.065	51.3	39.0	422.7 ^a	1.437	1.15	0.7
654 ^a	1.079	46.9	34.7	420.4 ^a	1.442	0.33	0.2
645 ^b	1.089	44.0	32.2	420.0 ^a	1.443	0.17	0.1
630 ^a	1.107	39.8	28.6				

^aC. T. Heycock and F. H. Neville.⁶¹

^bK. W. Andrews *et al.*⁶

TABLE III. Solubility of Silver in Liquid Zinc: Calculated^a

t, °C	$\frac{1000}{T, ^\circ\text{K}}$	Silver, w/o	Silver, a/o
450	1.383	4.20	2.55
500	1.293	8.61	5.51
550	1.215	16.1	10.1
600	1.145	28.1	19.5
650	1.083	46.1	33.2
700	1.028	71.6	53.1

^aCalculated from empirical equations.

ALUMINUM-ZINC

A. Phase Information

1. Phase Diagram

The complete phase diagram for the aluminum-zinc system is reported in Hansen and Anderko⁵⁰ (p. 149). A eutectic occurs at 88.7 a/o zinc and 382°C. The two solid phases in equilibrium at the eutectic are α_1 -Al (66.5 a/o zinc) and zinc (97.6 a/o zinc).

2. Intermetallic Phases

A range of solid solutions is given in detail in Hansen and Anderko. The aluminum-rich solid phase in equilibrium with the liquid solutions is a solid solution of zinc in aluminum.

B. Solubility Data

Pelzel¹¹⁸ and Gebhardt⁴³ determined the solubility of aluminum in liquid zinc by thermal analysis over the range of 380-562°C. These data are in good agreement with other data reported in Hansen and Anderko. The direct measurements are given in Fig. 2.

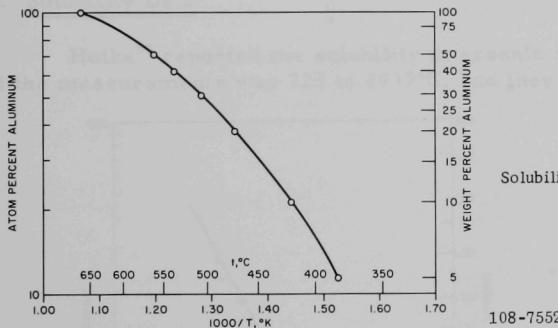


Fig. 2
Solubility of Aluminum in Liquid Zinc

Experimental data are given in Table IV, and interpolated values of the solubility (from Fig. 2) at 50°C intervals are presented in Table V.

TABLE IV. Solubility of Aluminum in Liquid Zinc: Experimental Data^{a,b}

t, °C	$\frac{1000}{T, ^\circ K}$	Aluminum, w/o		t, °C	$\frac{1000}{T, ^\circ K}$	Aluminum, a/o	
		Aluminum, w/o	Aluminum, a/o			Aluminum, w/o	Aluminum, a/o
562	1.197	50	70.8	472	1.342	20	37.7
537	1.234	40	61.8	420	1.443	10	21.2
507	1.282	30	50.9	382	1.526	5	11.3

^aE. Pelzel.¹¹⁸^bE. Gebhardt.⁴³TABLE V. Solubility of Aluminum in Liquid Zinc: Calculated^a

t, °C	$\frac{1000}{T, ^\circ K}$	Aluminum, w/o	Aluminum, a/o
550	1.215	46.3	70.0
500	1.293	26.9	45.3
450	1.383	14.4	27.4
400	1.486	7.0	15.5
350	1.605	3.3	8.0

^aRead from smooth curve of Fig. 2.

ARSENIC-ZINC

A. Phase Information

1. Phase Diagram

The phase diagram for arsenic-zinc is reported in Hansen and Anderko⁵⁰ (p. 186). Two congruently melting compounds are indicated.

2. Intermetallic Phases

The structures of arsenic-zinc intermetallic phases given by Stanton et al.¹³⁹ (p. 11) in their review are:

Compound	Crystal Class	Lattice Parameters, Å	References
As_2Zn_3	Tetragonal	$a = 11.78$ $c = 23.65$	30, 102, 138
As_2Zn	Orthorhombic	$a = 7.73$ $b = 8.00$ $c = 36.35$	138

B. Solubility Data

Heike⁵⁴ reported the solubility of arsenic in liquid zinc. The range of the measurements was 725 to 1015°C, and they are plotted in Fig. 3.

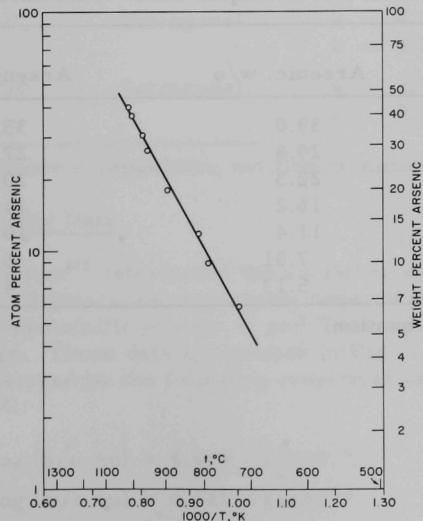


Fig. 3
Solubility of Arsenic
in Liquid Zinc

The solid phase in equilibrium with the solution is Zn_3As_2 . The direct measurements may be represented by the following empirical equations over the range of 725 to 1015°C:

$$\log (a/o As) = 4.487 - 3736T^{-1}$$

$$\log (w/o As) = 4.451 - 3641T^{-1}$$

Experimental data are given in Table VI, and calculated values of the solubility at 50°C intervals are presented in Table VII.

TABLE VI. Solubility of Arsenic in Liquid Zinc: Experimental Data^a

t, °C	$\frac{1000}{T, ^\circ K}$	Arsenic, w/o	Arsenic, a/o
1015	0.776	43.4	40.0
1006	0.782	40.0	36.8
970	0.804	33.5	30.4
955	0.814	30.0	27.2
883	0.865	20.0	17.9
815	0.919	13.2	11.7
792	0.939	10.0	8.8
725	1.002	6.6	5.8

^aW. Heike.⁵⁴

TABLE VII. Solubility of Arsenic in Liquid Zinc: Calculated^a

t, °C	$\frac{1000}{T, ^\circ K}$	Arsenic, w/o	Arsenic, a/o
1000	0.786	39.0	35.7
950	0.818	29.8	27.1
900	0.852	22.3	20.1
850	0.890	16.2	14.5
800	0.932	11.4	10.1
750	0.977	7.81	6.85
700	1.028	5.13	4.45

^aCalculated from empirical equation.

GOLD-ZINC

A. Phase Information1. Phase Diagram

The phase diagram for the system gold-zinc is reported by Hansen and Anderko⁵⁰ (p. 242). A complex series of intermediate phases with wide composition ranges is shown.

2. Intermetallic Phases

The structures of gold-zinc intermetallic phases given by Stanton *et al.*¹³⁹ (pp. 6 and 7) in their review are:

Compound	Crystal Class	Lattice Parameters, Å	References
AuZn ₆ *	Hexagonal	a = 2.82 c = 4.38	51, 112, 149
AuZn ₃ *	Cubic	a = 7.88	51, 112, 149
AuZn ₂ *	Cubic	a = 11.17	51, 112
Au ₅ Zn ₈ *	Cubic	a = 9.242	15, 51, 149
AuZn*	Cubic	a = 3.102	1, 51, 110, 149
Au ₃ Zn(α)*	Cubic	a = 4.039	76, 121, 125
Au ₃ Zn(α')*	Tetragonal	a = 4.034 c = 4.115	76, 121, 125
Au ₃ Zn(α'')*	Tetragonal	a = 3.956 ± 0.003 c = 8.323 ± 0.0012	76, 121, 125

*Approximate composition, not line compounds.

B. Solubility Data

Saldau¹²⁶ determined the solubility of gold in liquid zinc by thermal analysis. Saldau's measurements covered the range of 423-644°C. Two different intermetallic phases, ϵ and γ , are in equilibrium with liquid in this range. These data are plotted in Fig. 4. The experimental data may be represented by the following empirical equations over the range of 400-650°C:

$$\log (a/o \text{ Au}) = 4.444 - 2683T^{-1};$$

$$\log (w/o \text{ Au}) = 4.131 - 2143T^{-1}.$$

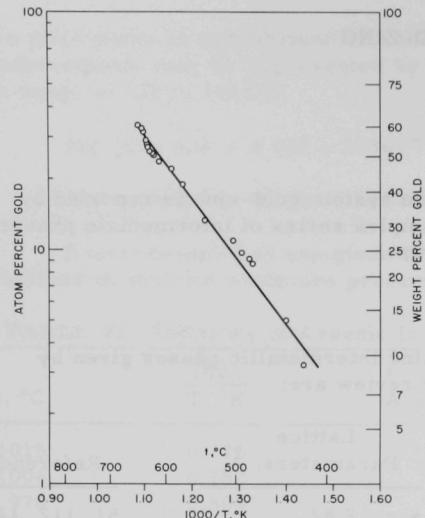


Fig. 4
Solubility of Gold in Liquid Zinc

108-7550

Experimental data are given in Table VIII, and calculated values of the solubility are given at 50°C intervals in Table IX.

TABLE VIII. Solubility of Gold in Liquid Zinc: Experimental Data^a

$t, ^\circ C$	$\frac{1000}{T, ^\circ K}$	Gold, w/o	Gold, a/o	$t, ^\circ C$	$\frac{1000}{T, ^\circ K}$	Gold, w/o	Gold, a/o
644	1.090	60.33	33.53	589	1.160	45.96	22.00
637	1.099	59.39	32.67	572	1.183	41.29	18.92
635	1.101	58.12	31.52	540	1.230	31.63	13.30
632	1.105	55.06	28.91	503	1.288	27.13	10.99
630	1.107	53.56	27.68	491	1.309	24.55	9.75
627	1.111	52.82	27.08	484	1.321	23.30	9.16
624	1.115	51.48	26.04	479	1.330	22.32	8.70
619	1.121	50.48	25.28	441	1.400	13.75	5.02
617	1.123	50.17	25.03	423	1.436	9.14	3.23
609	1.134	48.33	23.69	419	1.445	0.00	0.00

^aP. Saldaa.¹²⁶

TABLE IX. Solubility of Gold in Liquid Zinc: Calculated^a

$t, ^\circ C$	$\frac{1000}{T, ^\circ K}$	Gold, w/o	Gold, a/o	$t, ^\circ C$	$\frac{1000}{T, ^\circ K}$	Gold, w/o	Gold, a/o
650	1.083	64.4	34.5	500	1.293	22.9	9.39
600	1.145	47.5	23.5	450	1.383	14.7	5.40
550	1.215	33.7	15.3	400	1.486	8.86	2.86

^aCalculated from empirical equations.

BARIUM-ZINC

A. Phase Information

1. Phase Diagram

The zinc-rich portion of the phase diagram is reported in Hansen and Anderko⁵⁰ (p. 277). However, recent direct measurements of the solubility of barium in zinc^{65,72} differ markedly from the data of Kornilov⁷⁵ reported by Hansen and Anderko. Kornilov was unable to detect a zinc-rich eutectic.

2. Intermetallic Phases

The structures of barium-zinc intermetallic phases given by Stanton et al. (p. 8) in their review are:

Compound	Crystal Class	Lattice Parameters, Å	References
BaZn ₁₃	Cubic	a = 12.33	69
BaZn ₅	Orthorhombic	a = 5.32 b = 8.44 c = 10.78	8, 10

The BaZn₁₃ intermetallic is assumed to be the solid phase in equilibrium with the zinc-rich liquid solutions.

B. Solubility Data

Knighton⁷² and Johnson and Anderson⁶⁵ determined the solubility of barium in liquid zinc by analyzing filtered samples of the saturated liquid phase.

Knighton's measurements covered the range of 645-797°C; Johnson and Anderson's measurements covered the range of 535-693°C. The agreement between the two sets of measurements is satisfactory, as seen in Fig. 5. The data of Kornilov are seen to be generally several orders of magnitude greater than the direct measurements. The methods used by Kornilov are unsuited for systems with very small solubilities. The direct measurements may be represented by the following empirical equations over the range of 535-750°C:

$$\log (a/o \text{ Ba}) = 9.436 - 9974T^{-1};$$

$$\log (w/o \text{ Ba}) = 9.750 - 9967T^{-1}.$$

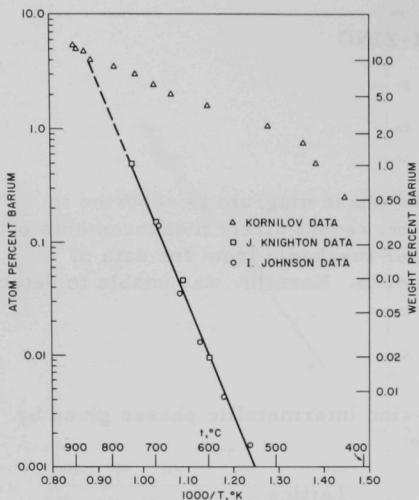


Fig. 5

Solubility of Barium in Liquid Zinc

108-7546

Experimental data are given in Table X, and calculated values of the solubility at 50°C intervals in Table XI.

TABLE X. Solubility of Barium in Liquid Zinc: Experimental Data

$t, ^\circ\text{C}$	$\frac{1000}{T, ^\circ\text{K}}$	Barium, w/o	Barium, a/o
748 ^a	0.979	1.02	0.490
697 ^a	1.031	0.317	0.151
693 ^b	1.035	0.294	0.140
651 ^a	1.082	0.074	0.0352
645 ^b	1.089	0.097	0.0460
615 ^b	1.126	0.0273	0.0130
598 ^a	1.146	0.0200	0.00952
576 ^b	1.178	0.00885	0.00421
535 ^b	1.237	0.00327	0.00156

^aJ. B. Knighton.⁷²^bI. Johnson and K. E. Anderson.⁶⁵TABLE XI. Solubility of Barium in Liquid Zinc: Calculated^a

$t, ^\circ\text{C}$	$\frac{1000}{T, ^\circ\text{K}}$	Barium, w/o	Barium, a/o
500	1.293	0.000723	0.000344
550	1.215	0.00439	0.00209
600	1.145	0.0217	0.0103
650	1.083	0.090	0.0428
700	1.028	0.323	0.154
750	0.977	1.022	0.488
800	0.932	2.90	1.388
850	0.890	7.53	3.60
900	0.852	18.0	8.60

^aCalculated from empirical equations.

BERYLLIUM-ZINC

A. Phase Information

1. Phase Diagram

No data have been reported for the phase diagram of beryllium-zinc.

2. Intermetallic Phase

No data are available on beryllium-zinc intermetallic phases.

B. Solubility Data

Johnson and Anderson^{65,66} determined the solubility of beryllium in liquid zinc by analyzing filtered samples of the saturated liquid phase. Their measurements covered the range of 429-828°C. The retrograde solubility shown in the range of 663-828°C is somewhat questionable because it was not certain that the liquid phase was saturated. The data of Johnson and Anderson are plotted in Fig. 6. The experimental data may be represented by the following empirical equations:

429-693°C

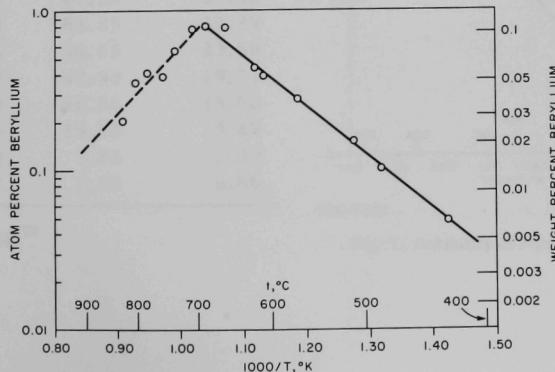
$$\log (a/o \text{ Be}) = 3.221 - 3188T^{-1};$$

$$\log (w/o \text{ Be}) = 2.379 - 3204T^{-1}.$$

693-828°C

$$\log (a/o \text{ Be}) = -4.401 + 4172T^{-1};$$

$$\log (w/o \text{ Be}) = -5.268 + 4818T^{-1}.$$



108-7553

Fig. 6. Solubility of Beryllium in Liquid Zinc

Experimental data are given in Table XII, and calculated values of the solubility at 50°C intervals in Table XIII.

TABLE XII. Solubility of Beryllium in Liquid Zinc: Experimental Data

t, °C	$\frac{1000}{T, ^\circ K}$		Beryllium, w/o	Beryllium, a/o	$\frac{1000}{T, ^\circ K}$			
	Beryllium, w/o	Beryllium, a/o				Beryllium, w/o	Beryllium, a/o	
828 ^b	0.908	0.0278	0.201		663 ^b	1.068	0.107	0.772
805 ^b	0.928	0.0490	0.354		630 ^a	1.107	0.0602	0.435
783 ^b	0.947	0.0560	0.404		611 ^a	1.131	0.0536	0.388
757 ^b	0.971	0.053	0.384		571 ^a	1.185	0.0398	0.274
737 ^b	0.990	0.077	0.556		512 ^a	1.274	0.0206	0.149
709 ^b	1.018	0.106	0.764		486 ^a	1.317	0.0152	0.110
689 ^b	1.039	0.110	0.793		429 ^a	1.424	0.0064	0.047

^aI. Johnson and K. E. Anderson.⁶⁶

^bI. Johnson and K. E. Anderson.⁶⁵

TABLE XIII. Solubility of Beryllium in Liquid Zinc: Calculated^a

t, °C	$\frac{1000}{T, ^\circ K}$		Beryllium, w/o	Beryllium, a/o	$\frac{1000}{T, ^\circ K}$			
	Beryllium, w/o	Beryllium, a/o				Beryllium, w/o	Beryllium, a/o	
850	0.890	0.0284	0.205		600	1.145	0.0513	0.372
800	0.932	0.0426	0.307		550	1.215	0.0306	0.223
750	0.977	0.0656	0.473		500	1.293	0.0172	0.125
700	1.028	0.112	0.773		450	1.383	0.0089	0.065
650	1.083	0.0812	0.586		400	1.486	0.0042	0.0305

^aCalculated from empirical equations.

BISMUTH-ZINC

A. Phase Information

1. Phase Diagram

The phase diagram for the bismuth-zinc system is reported in Hansen and Anderko⁵⁰ (p. 347). This system possesses a liquid-miscibility gap. The most recent determination of the liquid-miscibility gap has been made by Kleppa⁷⁰ by means of activity measurements.

2. Intermetallic Phases

No intermetallic phases have been found.

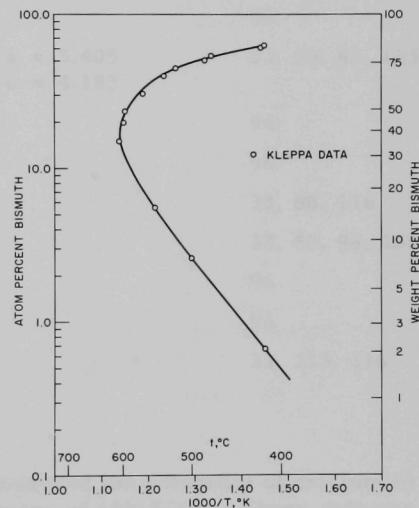
B. Solubility Data

Kleppa⁷⁰ determined the solubility of bismuth in liquid zinc over the range of 416-605°C. His data are given in Table XIV and plotted in Fig. 7. In Table XV are given data at 50°C intervals taken from Fig. 7.

TABLE XIV. Solubility of Bismuth in Liquid Zinc: Experimental Data^a

$t, ^\circ\text{C}$	$\frac{1000}{T, ^\circ\text{K}}$	Bismuth, w/o	Bismuth, a/o
416	1.451	84.47	63.00
420	1.443	83.07	60.55
475	1.337	78.59	53.45
482	1.324	76.24	50.11
520	1.261	72.14	44.77
536	1.236	67.68	39.58
567	1.190	58.25	30.39
595	1.152	49.65	23.58
597	1.149	43.98	19.72
605	1.139	36.06	15.00
550	1.215	15.65	5.49
500	1.293	7.83	2.59
416	1.451	2.20	0.66

^aO. J. Kleppa.⁷⁰



108-7542

Fig. 7. Solubility of Bismuth in Liquid Zinc

TABLE XV. Solubility of Bismuth in Liquid Zinc: Estimated^a

t, °C	1000 T, °K	Bismuth Branch		Zinc Branch	
		Bismuth, w/o	Bismuth, a/o	Bismuth, w/o	Bismuth, a/o
605	1.139	36.1	15.0	36.1	15.0
600	1.145	44.4	20.0	34.2	14.0
575	1.179	56.8	29.2	22.9	8.2
550	1.215	65.2	37.0	15.7	5.5
525	1.253	70.7	43.1	11.2	3.8
500	1.293	74.5	47.0	7.9	2.6
475	1.337	77.8	52.3	5.47	1.78
450	1.383	80.5	56.4	3.64	1.17
425	1.432	83.0	60.3	2.41	0.77
416	1.451	84.5	63.0	2.08	0.66

^aObtained from Fig. 7.

CALCIUM-ZINC

A. Phase Information1. Phase Diagram

The phase diagram for the calcium-zinc system is reported in Hansen and Anderdo⁵⁰ (pp. 412-414). The data of Messing *et al.*⁹⁶ show a similarly-shaped but more complex diagram (see intermetallic phases). A complex sequence of intermediate phases with narrow composition ranges is shown.

2. Intermetallic Phases

The structures of calcium-zinc intermetallic phases given by Stanton *et al.*¹³⁹ (pp. 7-8) in their review and by Messing *et al.*⁹⁶ are:

Compound	Crystal Class	Lattice Parameters, Å	References
CaZn ₁₃	Cubic	a = 12.13 ± 0.005	33, 69, 80, 103
CaZn ₁₁			96
CaZn ₅	Hexagonal	a = 5.405 c = 4.183	33, 53, 80, 103
Ca ₇ Zn ₂₀			96
CaZn ₂			96
Ca ₂ Zn ₃			33, 80, 116
CaZn			33, 80, 96, 103
(Ca ₇ Zn ₄)			96
(Ca ₃ Zn)			96
Ca ₄ Zn			33, 115, 116

B. Solubility Data

Donski³³ and Messing *et al.*⁹⁶ measured the solubility of calcium in liquid zinc by thermal analysis in the range of 650-725°C. These data are plotted in Fig. 8. The experimental data may be represented by the following empirical equations over the range 650-725°C (the principal compound in this range is CaZn₁₃):

$$\log (a/o \text{ Ca}) = 8.326 - 7395T^{-1};$$

$$\log (w/o \text{ Ca}) = 8.268 - 7535T^{-1}.$$

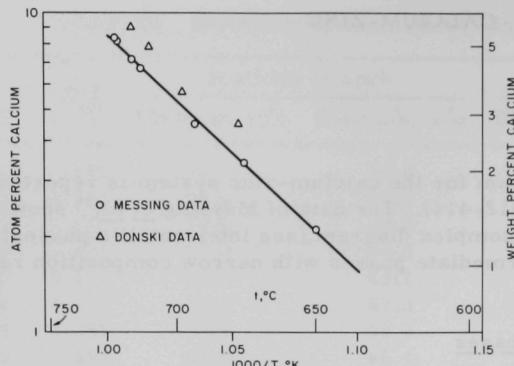


Fig. 8

Solubility of Calcium
in Liquid Zinc

108-7556

Experimental data are given in Table XVI, and calculated values of the solubility at 20°C intervals in Table XVII.

TABLE XVI. Solubility of Calcium in Liquid Zinc:
Experimental Data

$t, ^\circ\text{C}$	$1000/T, ^\circ\text{K}$	Calcium, w/o	Calcium, a/o
650 ^a	1.083	1.30	2.1
675 ^a	1.055	2.11	3.4
693 ^a	1.035	2.81	4.5
714 ^a	1.013	4.2	6.7
717 ^a	1.001	4.5	7.14
723 ^a	1.004	5.2	8.2
724 ^a	1.003	5.3	8.33
717 ^b	1.001	5.7	9.0
710 ^b	1.017	4.9	7.8
698 ^b	1.030	3.5	5.6
677 ^b	1.052	2.8	4.5

^aA. F. Messing, M. D. Adams, and R. K. Steunenberg.⁹⁶^bL.-Donski.³³TABLE XVII. Solubility of Calcium in Liquid Zinc:
Calculated^a

$t, ^\circ\text{C}$	$1000/T, ^\circ\text{K}$	Calcium, w/o	Calcium, a/o
720	1.007	4.79	7.57
700	1.028	3.33	5.30
680	1.049	2.31	3.71
660	1.072	1.56	2.51
640	1.095	1.00	1.69

^aCalculated from empirical equations.

CADMIUM-ZINC

A. Phase Information

1. Phase Diagram

The phase diagram for the cadmium-zinc system is reported by Hansen and Anderko⁵⁰ (p. 447). This is a simple eutectic system with the eutectic occurring at 265°C and 26.7 a/o zinc. There is a small mutual solubility of the solid phases.

2. Intermetallic Phases

The cadmium-rich solid phase in equilibrium with the liquid at the eutectic contains approximately 5 a/o zinc.

B. Solubility Data

Heycock and Neville,⁵⁹ Lorenz and Plumbridge,⁸⁶ and Bruni, Sandonnini, and Quercigh¹⁷ determined the solubility of cadmium in liquid zinc by thermal analysis. Their measurements covered the range of 265-320°C and are plotted in Fig. 9

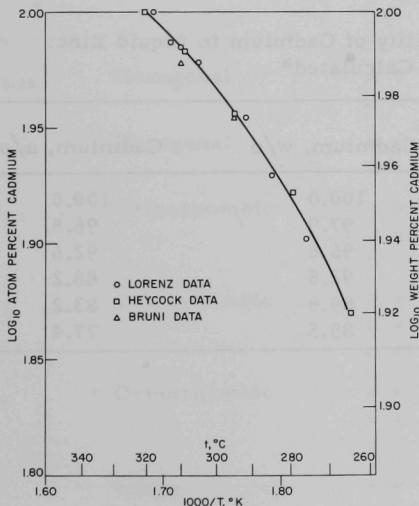


Fig. 9
Solubility of Cadmium
in Liquid Zinc

108-7571

Experimental data are given in Table XVIII, and interpolated values of the solubility at 10°C intervals in Table XIX.

TABLE XVIII. Solubility of Cadmium in Liquid Zinc:
Experimental Data

$t, {}^{\circ}\text{C}$	$\frac{1000}{T, {}^{\circ}\text{K}}$	Cadmium, w/o	Cadmium, a/o
320.5 ^a	1.684	100.0	100.0
318 ^b	1.692	100.0	100.0
313 ^b	1.706	98.8	98.0
310 ^b	1.715	97.9	96.5
310 ^c	1.715	97.0	95.1
309 ^a	1.718	97.7	96.1
305 ^b	1.730	97.0	95.1
295 ^a	1.760	94.2	90.4
292 ^b	1.769	93.9	90.0
285 ^b	1.792	90.6	85.0
279.4 ^a	1.810	89.8	83.6
276 ^b	1.821	86.9	79.8
264.7 ^a	1.859	83.3	74.3

^aC. T. Heycock and F. H. Neville.⁵⁹

^bR. Lorenz and D. Plumbridge.⁸⁶

^cG. Bruni, C. Sandonnini, and E. Quercigh.¹⁷

TABLE XIX. Solubility of Cadmium in Liquid Zinc:
Calculated^a

$t, {}^{\circ}\text{C}$	$\frac{1000}{T, {}^{\circ}\text{K}}$	Cadmium, w/o	Cadmium, a/o
321	1.686	100.0	100.0
310	1.715	97.9	96.5
300	1.745	95.6	92.6
290	1.776	92.8	88.2
280	1.808	89.8	83.2
270	1.841	85.5	77.4

^aTaken from Fig. 9.

CERIUM-ZINC

A. Phase Information

1. Phase Diagram

The zinc-rich portion of the phase diagram for the cerium-zinc system is reported in Hansen and Anderko⁵⁰ (p. 465). Recent data by Veleckis¹⁴⁵ indicate a more complex structure.

2. Intermetallic Phases

The structures of cerium-zinc intermetallic phases given by Stanton *et al.*¹³⁹ (p. 9) in their review and by Veleckis¹⁴⁵ and Chiotti and Mason²⁷ are:

Compound	Crystal Class	Lattice Parameters, Å	References
CeZn ₁₁	Tetragonal	a = 10.66 c = 6.86	27, 128, 134, 145
CeZn _{8.5}	Rhombohedral	a = 9.0708 c = 13.2844	27, 145
CeZn ₇			27, 145
CeZn _{5.25}	Hexagonal	a = 5.4163 c = 4.2647	27, 145
CeZn _{4.4}	Hexagonal	a = 14.600 c = 14.110	27, 145
CeZn _{3.6}	Orthorhombic	a = 4.5215 b = 8.8855 c = 13.463	27, 145
CeZn ₃	Orthorhombic	a = 4.620 b = 10.440 c = 6.640	27, 145
CeZn ₂	Orthorhombic	a = 4.633 b = 7.538 c = 7.499	27, 145
CeZn	Cubic	a = 3.704	63, 124, 145

B. Solubility Data

The solubility of cerium in liquid zinc was determined by Schramm¹³⁴ by thermal analysis and by Knighton⁷³ by analyzing filtered samples of the saturated liquid phase.

742-972°C. As seen from Fig. 10, the data have a somewhat different slope. This suggests that the solid phase in the range of 750-970°C may be the CeZn_{8.5}. CeZn₁₁ is the equilibrium phase over the range of 500-750°C. The direct measurements may be represented by the following empirical equations over the range of 500-750°C:

$$\log (a/o \text{ Ce}) = 7.217 - 7450T^{-1};$$

$$\log (w/o \text{ Ce}) = 7.487 - 7390T^{-1}.$$

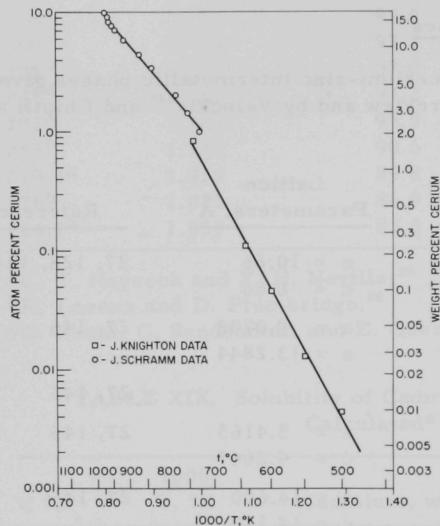


Fig. 10

Solubility of Cerium
in Liquid Zinc

108-7795

Experimental data are given in Table XX and calculated values of the solubility at 50°C intervals in Table XXI.

TABLE XX. Solubility of Cerium in Liquid Zinc:
Experimental Data

t, °C	$\frac{1000}{T, ^\circ K}$	Cerium, w/o	Cerium, a/o
972 ^a	0.803	19.2	10.0
964 ^b	0.808	17.7	9.1
960 ^b	0.811	16.2	8.3
950 ^b	0.818	15.2	7.7
942 ^b	0.823	14.0	7.1
916 ^b	0.841	11.6	5.8
874 ^b	0.872	9.1	4.4
840 ^b	0.898	7.0	3.4
780 ^b	0.949	4.2	2.0
755 ^b	0.973	3.0	1.42
742 ^b	0.985	1.75	0.825
728 ^b	0.999	2.1	0.99
642 ^b	1.093	0.245	0.110
599 ^b	1.147	0.098	0.046
549 ^b	1.216	0.028	0.013
501 ^b	1.292	0.0099	0.0044

TABLE XXI. Solubility of Cerium in Liquid Zinc:
Calculated^a

t, °C	$\frac{1000}{T, ^\circ K}$	Cerium, w/o	Cerium, a/o
750	0.977	2.88	1.36
700	1.028	0.76	0.36
650	1.083	0.30	0.14
600	1.145	0.100	0.049
550	1.215	0.032	0.0146
500	1.293	0.0086	0.0038

^aCalculated from empirical equations.

COBALT-ZINC

A. Phase Information

1. Phase Diagram

The phase diagram for cobalt-zinc is reported in Hansen and Anderko⁵⁰ (p. 521). A complex sequence of intermediate phases with wide composition ranges is shown.

2. Intermetallic Phases

The structures of cobalt-zinc intermetallic phases given by Stanton et al. (p. 13) in their review are:

<u>Compound</u>	<u>Crystal Class</u>	<u>Lattice Parameters, Å</u>	<u>References</u>
CoZn* (β)	Cubic	a = 6.314-6.369	131
CoZn ₁₃ * (γ_2)	Monoclinic	a = 13.48 b = 7.50 c = 5.07	44
Co ₅ Zn ₂₁ * (γ)	Cubic	a = 8.90-8.97	36, 131

*Approximate composition, not line compounds.

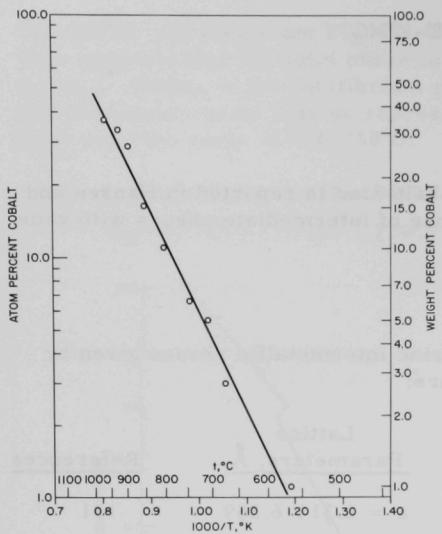
B. Solubility Data

Schramm¹³¹ used thermal analysis to determine the solubility of cobalt in liquid zinc over the range of 566-966°C. There are several phases in this region (β , γ_1 , γ). The experimental data of Schramm are plotted in Fig. 11 and tabulated in Table XXII. The experimental data may be represented by the following empirical equations over the range of 566-966°C:

$$\log (a/o \text{ Co}) = 4.988 - 4214T^{-1};$$

$$\log (w/o \text{ Co}) = 5.066 - 4342T^{-1}.$$

Calculated values of the solubility at 50°C intervals are presented in Table XXIII.



108-7792

Fig. 11. Solubility of Cobalt in Liquid Zinc

TABLE XXII. Solubility of Cobalt in Liquid Zinc: Experimental Data^a

$t, ^\circ\text{C}$	$\frac{1000}{T, ^\circ\text{K}}$	Cobalt, w/o	Cobalt, a/o
966	0.807	34.5	36.9
924	0.835	31.5	33.9
895	0.856	24	29.1
855	0.886	15	16.4
805	0.928	10	11.0
746	0.981	6	6.6
725	1.002	5	5.5
675	1.055	2.7	3.0
566	1.192	0.9	1.1

^aJ. Schramm.¹³¹TABLE XXIII. Solubility of Cobalt in Liquid Zinc: Calculated^a

$t, ^\circ\text{C}$	$\frac{1000}{T, ^\circ\text{K}}$	Cobalt, w/o	Cobalt, a/o
1000	0.785	45.2	47.6
950	0.818	32.8	34.9
900	0.852	23.2	24.9
850	0.890	15.8	17.2
800	0.932	10.5	11.5
750	0.977	6.64	7.40
700	1.028	4.02	4.55
650	1.083	2.30	2.65
600	1.145	1.24	1.45
550	1.215	0.618	0.74
500	1.293	0.282	0.34

^aCalculated from empirical equations.

CHROMIUM-ZINC

A. Phase Information

1. Phase Diagram

The phase diagram for the chromium-zinc system is given by Hansen and Anderko⁵⁰ (p. 572) for the zinc-rich portion of the diagram (1-7 a/o chromium).

2. Intermetallic Phases

The structure of the chromium-zinc intermetallic phase (CrZn_{10}) given by Stanton *et al.*¹³⁹ (p.11) in their review is:

<u>Compound</u>	<u>Crystal Class</u>	<u>Lattice Parameters, Å</u>	<u>References</u>
CrZn_{10}^*	Hexagonal	$a = 12.91$ $c = 30.5$	49, 57, 85

*Hansen and Anderko report data indicating that this compound is CrZn_{17} .

B. Solubility Data

Chiotti and Parry,²⁴ Lihl and Jenitschek,⁸⁵ and Weisse, Blumenthal, and Haneman¹⁴⁸ used microscopic analysis to determine the solubility of chromium in liquid zinc. Their data over the range of 415-500°C are shown in Fig. 12. The direct measurements may be represented by the following empirical equations over the range of 410-470°C:

$$\log (\text{a/o Cr}) = 8.530 - 6191T^{-1};$$

$$\log (\text{w/o Cr}) = 8.136 - 5984T^{-1}.$$

Experimental data are given in Table XXIV and calculated values of the solubility at 10°C intervals in Table XXV.

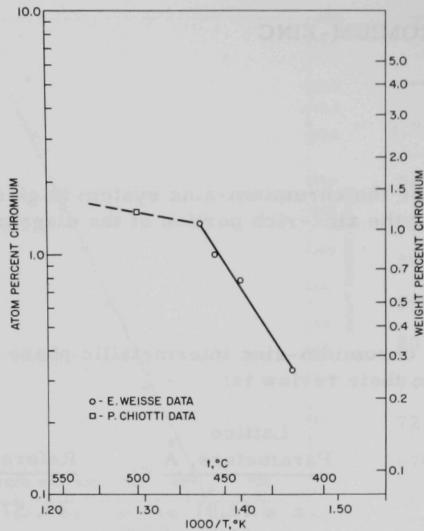


Fig. 12

Solubility of Chromium
in Liquid Zinc

108-7790

TABLE XXIV. Solubility of Chromium in
Liquid Zinc: Experimental Data

$t, ^\circ\text{C}$	$\frac{1000}{T, ^\circ\text{K}}$	Chromium, w/o	Chromium, a/o
500 ^a	1.293	1.2	1.5
463 ^b	1.358	0.98	1.33
455 ^b	1.373	0.79	0.99
440 ^b	1.402	0.64	0.78
415 ^c	1.453	0.26	0.33

^aP. Chiotti and S. J. S. Parry.²⁴^bF. Lihl and P. Jenitschek.⁶⁵^cE. Weisse, A. Blumenthal, and H. Hanemann.¹⁴⁸

TABLE XXV. Solubility of Chromium in
Liquid Zinc: Calculated^a

$t, ^\circ\text{C}$	$\frac{1000}{T, ^\circ\text{K}}$	Chromium, w/o	Chromium, a/o
470	1.3456	1.21	1.58
460	1.3640	0.94	1.22
450	1.3828	0.73	0.93
440	1.4022	0.56	0.71
430	1.4222	0.42	0.53
420	1.4427	0.32	0.40
410	1.4638	0.24	0.29

^aCalculated from empirical equations.

COPPER-ZINC

A. Phase Information

1. Phase Diagram

The phase diagram for the copper-zinc system is given by Hansen and Anderko⁵⁰ (p. 650). A complex sequence of intermediate phases of wide composition ranges is shown.

2. Intermetallic Phases

The structures of the copper-zinc intermetallic phases given by Stanton *et al.*¹³⁹ (pp. 5-6) in their review are:

Compound	Crystal Class	Lattice Parameters, Å	References
CuZn ₅ * (ε)	Hexagonal	a = 2.75 c = 4.30	109, 122
CuZn ₃ * (δ)	Cubic	a = 3.016	109, 122, 135
Cu ₅ Zn ₈ * (γ)	Cubic	a = 8.879	13, 16, 64, 109, 122
CuZn* (β)	Cubic	a = 2.96	12, 64, 109, 114, 122

*Approximate composition, not line compounds.

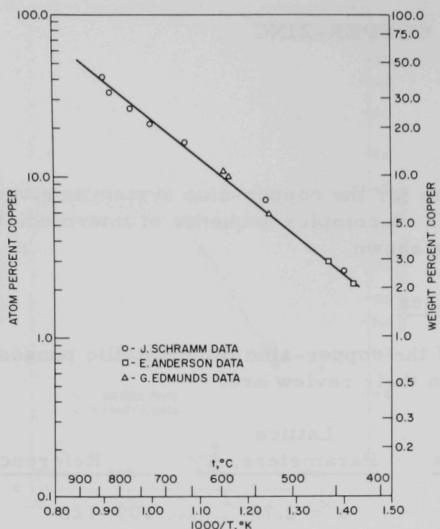
B. Solubility Data

The solubility of copper in liquid zinc has been determined micrographically by Schramm,¹³⁰ Anderson *et al.*,³ and Edmunds³⁴ over the zinc-rich region (0 to 40 a/o Cu) in the corresponding range of 420-835°C. There are several phases in this region. Their data are plotted in Fig. 13. The direct measurements may be represented by the following empirical equations over the range of 430-900°C:

$$\log (a/o \text{ Cu}) = 3.752 - 2389T^{-1};$$

$$\log (w/o \text{ Cu}) = 3.750 - 2397T^{-1}.$$

Experimental data are given in Table XXVI and calculated values of the solubility at 50°C intervals in Table XXVII.



108-7794

TABLE XXVI. Solubility of Copper in Liquid Zinc: Experimental Data

$t, {}^{\circ}\text{C}$	$\frac{1000}{T, \text{K}}$	Copper, w/o	Copper, a/o
834 ^a	0.903	40	40.7
816 ^a	0.918	32.5	33.2
768 ^a	0.960	26	26.6
719 ^a	1.008	21	21.5
659 ^a	1.073	16	16.4
595 ^c	1.152	10.6	10.8
587 ^c	1.163	9.7	9.98
534 ^a	1.124	7.0	7.2
530 ^c	1.245	5.7	5.9
457 ^b	1.370	2.9	3.0
440 ^a	1.402	2.5	2.6
430 ^b	1.422	2.1	2.2
423.5 ^a	1.435	1.7	1.7

^aJ. Schramm.¹³⁰^bE. A. Anderson, et al.³^cG. Edmunds.³⁴TABLE XXVII. Solubility of Copper in Liquid Zinc: Calculated^a

$t, {}^{\circ}\text{C}$	$\frac{1000}{T, \text{K}}$	Copper, w/o	Copper, a/o
900	0.852	51.6	52.2
850	0.890	41.3	42.2
800	0.032	32.8	33.6
750	0.977	25.5	26.1
700	1.028	19.3	19.8
650	1.083	14.2	14.6
600	1.145	10.10	10.37
550	1.215	6.88	7.07
500	1.293	4.46	4.59
450	1.383	2.72	2.81
425	1.432	2.03	2.09

^aCalculated from empirical equations.

TABLE XXVII

IRON-ZINC

A. Phase Information1. Phase Diagram

The phase diagram for the iron-zinc system is reported in Hansen and Anderko⁵⁰ (p. 738) for the entire range of composition. The zinc-rich portion of the phase diagram is also reported by Hansen and Anderko⁵⁰ (p. 739). Several intermediate phases of wide composition range are shown.

2. Intermetallic Phases

The structures of iron-zinc intermetallic phases given by Stanton *et al.*¹³⁹ (p. 13) in their review are:

Compound	Crystal Class	Lattice Parameters, Å	References
FeZn ₇₋₁₀ * (δ_1)	Hexagonal	a = 12.82 c = 57.7	7, 84, 108, 131
FeZn ₁₃ (ξ)	Monoclinic	a = 13.67 b = 7.62 c = 5.07	48, 84, 131
Fe ₅ Zn ₂₁ * (Γ)	Cubic	a = 9.01	36, 84, 108, 131

*Approximate composition, not line compounds.

B. Solubility Data

Edmunds³⁴ and Truesdale, Wilcox, and Rodda¹⁴³ determined the solubility of iron in zinc by analyzing samples of the saturated-liquid phase. Edmunds' measurements covered the range of 420-672°C; Truesdale's measurements covered the range of 420-900°C. These data are shown in Fig. 14. There are three regions, corresponding to the following intermetallic compounds as the solid phase in equilibrium with the solution:

420-672°C: ζ , δ_1 , and δ phases;

672-782°C: Fe₅Zn₂₁ (Γ phase);

782-900°C: solid solution of zinc in γ iron.

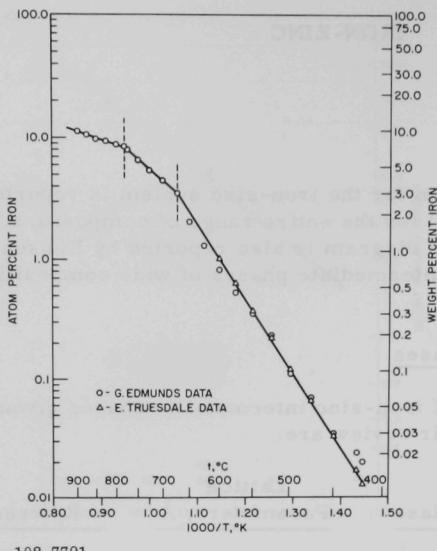


Fig. 14

Solubility of Iron
in Liquid Zinc

108-7791

The direct measurements may be represented by the following empirical equations over the indicated temperature ranges:

419.4-672°C

$$\log (a/o \text{ Fe}) = 7.213 - 6293T^{-1};$$

$$\log (w/o \text{ Fe}) = 7.152 - 6299T^{-1}.$$

672-782°C

$$\log (a/o \text{ Fe}) = 4.229 - 3485T^{-1};$$

$$\log (w/o \text{ Fe}) = 4.190 - 3511T^{-1}.$$

782-900°C

$$\log (a/o \text{ Fe}) = 2.157 - 1301T^{-1};$$

$$\log (w/o \text{ Fe}) = 2.127 - 1336T^{-1}.$$

Experimental data are given in Table XXVIII, and calculated values of the solubility at 50°C intervals in Table XXIX.

TABLE XXVIII. Solubility of Iron in Liquid Zinc: Experimental Data

t, °C	1000 T, °K	Edmunds ^a		Truesdale ^b	
		Iron, w/o	Iron, a/o	Iron, w/o	Iron, a/o
900	0.852			9.75	11.22
875	0.871			9.15	10.54
850	0.890			8.65	9.77
825	0.911			8.15	9.41
800	0.932			7.70	8.89
782	0.948			7.40	8.55
775	0.954			6.95	8.03
750	0.977			5.65	6.55
725	1.002			4.65	5.40
700	1.028			3.85	4.48
675	1.055			3.05	3.55
672	1.058	3.02	3.51	3.00	3.49
650	1.083			1.75	2.04
625	1.113			1.10	1.28
600	1.145	0.86	1.01	0.70	0.82
575	1.179	0.53	0.63	0.45	0.53
550	1.215	0.31 ₆	0.37	0.30	0.35
525	1.253	0.19	0.22	0.20	0.23
500	1.293	0.10 ₃	0.12	0.10	0.11
475	1.337	0.055	0.065	0.06	0.070
450	1.383	0.029	0.033	0.03	0.035
425	1.432	0.014 ₃	0.017	0.02	0.024
419.4	1.444	0.011	0.013	0.018	0.020

^aC. Edmunds.³⁴^bE. C. Truesdale, R. L. Wilcox, and J. L. Rodda.¹⁴³TABLE XXIX. Solubility of Iron in Liquid Zinc:
Calculated^a

t, °C	1000 T, °K	Iron, w/o	Iron, a/o
900	0.852	9.74	11.15
850	0.890	8.64	9.95
800	0.932	7.63	8.79
750	0.977	5.74	6.65
700	1.028	3.83	4.44
650	1.083	1.89	2.18
600	1.145	0.808	0.944
550	1.215	0.312	0.365
500	1.293	0.106	0.124
450	1.383	0.0312	0.0365
400	1.486	0.0076	0.0089

^aCalculated from empirical equations.

GALLIUM-ZINC

A. Phase Information1. Phase Diagram

The phase diagram for the gallium-zinc system is reported in Hansen and Anderko⁵⁰ (p. 762) for the entire range of composition. This is a simple eutectic system with the eutectic occurring at 25°C and 95 a/o gallium.

2. Intermetallic Phases

No intermetallic phases were found in this system.

B. Solubility Data

Heumann and Predel determined the liquidus by thermal analysis.⁵⁸ The experimental data are given in Table XXX, and interpolated values of the solubility at 25°C intervals in Table XXXI.

TABLE XXX. Liquid-phase Composition of Gallium-Zinc System: Experimental Data^a

t, °C	<u>1000</u> T, °K	Gallium, w/o	Gallium, a/o
82	2.816	90.69	90.13
87	2.777	89.75	89.14
119	2.550	85.36	84.54
158	2.319	79.00	77.91
175	2.231	74.02	72.76
198	2.122	69.13	67.74
224	2.011	61.48	59.95
237	1.960	56.50	54.91
254	1.897	51.48	49.88
266	1.855	46.44	44.85
278	1.814	42.57	41.01
294	1.763	36.52	35.05
309	1.718	31.40	30.03
323	1.677	26.21	24.90
340	1.631	20.94	19.90
373	1.548	11.00	10.39
378	1.536	10.47	9.88

^aT. Heumann and B. Predel.⁵⁸

TABLE XXXI. Liquid-phase Composition of Gallium-Zinc System: Calculated^a

t, °C	1000 T, °K	Gallium, w/o	Gallium, a/o
75	2.84	91.0	90.5
100	2.66	88.4	87.7
125	2.51	84.8	84.0
150	2.37	80.0	79.2
175	2.23	74.5	73.5
200	2.116	68.4	67.0
225	2.009	61.5	60.0
250	1.913	53.4	51.8
275	1.824	44.1	42.5
300	1.747	34.7	33.2
325	1.672	25.4	24.2
350	1.605	16.8	16.0
375	1.541	10.7	10.1

^aRead from a graph of the data.

GERMANIUM-ZINC

A. Phase Information1. Phase Diagram

The phase diagram for the germanium-zinc system is reported in Hansen and Anderko⁵⁰ (p. 779) for the entire range of composition. This is a simple eutectic system with the eutectic occurring at 398°C and 94.6 a/o zinc.

2. Intermetallic Phases

No intermetallic phases.

B. Solubility Data

Gebhardt⁴² determined the solubility of germanium in liquid zinc by thermal analysis. Thurmond and Kowalchik¹⁴² determined the solubility by holding high-purity single-crystal ingots of germanium with zinc in sealed silica tubes until equilibrium was established. The compositions of the saturated melts were obtained from the loss in weight of the germanium ingot. These data are shown in Fig. 15. The two sets of data are in

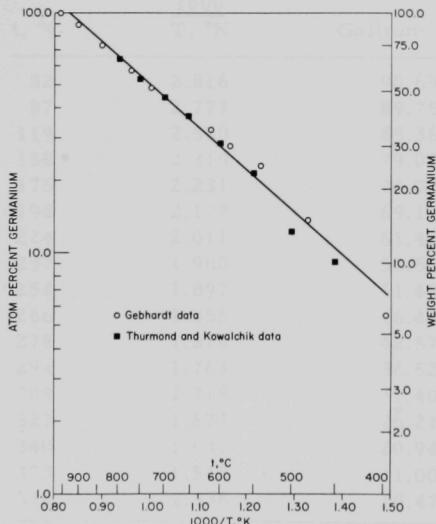


Fig. 15

Solubility of Germanium
in Liquid Zinc

excellent agreement and may be represented by the following empirical equations over the range of 450-960°C:

$$\log (a/o \text{ Ge}) = 3.431 - 1733T^{-1};$$

$$\log (w/o \text{ Ge}) = 3.379 - 1667T^{-1}.$$

Experimental data are given in Table XXXII, and calculated values of the solubility at 50°C intervals in Table XXXIII.

TABLE XXXII. Solubility of Germanium in Liquid Zinc:
Experimental Data

t, °C	1000 T, °K	Germanium, w/o	Germanium, a/o
958.5 ^a	0.812	100	100
905 ^a	0.849	90	89
840 ^a	0.898	75	73
770 ^a	0.959	60	57.5
720 ^a	1.007	51	48.4
615 ^a	1.126	35	32.7
585 ^a	1.165	30	27.9
540 ^a	1.230	25	23.1
480 ^a	1.328	15	13.7
398 ^a	1.490	6	5.5
450 ^b	1.383	10.0	9.14
500 ^b	1.293	16.2	14.8
550 ^b	1.215	23.1	21.3
600 ^b	1.145	31.0	28.8
655 ^b	1.077	39.3	36.8
700 ^b	1.028	46.6	44.0
750 ^b	0.977	55.6	53.0
800 ^b	0.932	66.0	63.6

^aE. Gebhardt.⁴²

^bC. D. Thurmond and M. Kowalchik.¹⁴²

TABLE XXXIII. Solubility of Germanium in Liquid Zinc:
Calculated^a

t, °C	1000 T, °K	Germanium, w/o	Germanium, a/o
900	0.852	90.9	90.1
850	0.890	78.6	77.4
800	0.932	66.9	65.3
750	0.977	56.3	54.7
700	1.028	46.3	44.6
650	1.083	37.5	35.8
600	1.145	29.6	28.0
550	1.215	22.6	21.1
500	1.293	16.7	15.5
450	1.383	11.8	10.8

^aCalculated from empirical equations.

INDIUM-ZINC

A. Phase Information1. Phase Diagram

The phase diagram for the indium-zinc system is reported in Hansen and Anderko⁵⁰ (p. 868). This is a simple eutectic system with the eutectic occurring at 143.5°C and 4.8 a/o indium.

2. Intermetallic Phases

No intermetallic phases were found in this system.

B. Solubility Data

Rhines and Grobe¹²³ and Valentiner¹⁴⁴ determined the liquidus by thermal analysis. Their measurements covered the range of 415-369°C. Experimental data are given in Table XXXIV, and calculated values of the solubility at 10°C intervals in Table XXXV.

TABLE XXXIV. Solubility of Indium in Liquid Zinc:
Experimental Data

t, °C	1000 T, °K	Indium, w/o	Indium, a/o
415 ^a	1.453	1.70	0.97
410.6 ^b	1.463	3.00	1.73
407 ^a	1.470	3.64	2.10
405 ^a	1.475	4.92	2.86
402.9 ^b	1.479	5.20	3.02
394.8 ^a	1.497	10.00	5.94
391.8 ^b	1.504	13.07	8.55
381 ^a	1.529	17.63	10.85
379.3 ^a	1.533	25.50	16.30
375.8 ^a	1.541	32.86	21.80
372.7 ^a	1.548	31.25	20.55
371 ^a	1.552	35.54	23.86
369 ^a	1.557	49.86	36.10

^aF. Rhines and A. Grobe.¹²³

^bS. Valentiner.¹⁴⁴

TABLE XXXV. Solubility of Indium in Liquid Zinc: Calculated^a

t, °C	1000 T, °K	Indium, w/o	Indium, a/o
420	1.443	1.70	0.937
410	1.464	3.15	1.80
400	1.486	5.93	3.54
390	1.508	11.39	7.08
380	1.531	22.3	14.49
370	1.555	44.6	30.3
360	1.579	91.2	64.9

^aTaken from a plot of the experimental data.

LANTHANUM-ZINC

A. Phase Information1. Phase Diagram

The phase diagram for the lanthanum-zinc system is reported by Hansen and Anderko⁵⁰ for the entire range of composition (p. 895) and for the zinc-rich portion (p. 896). The sequence of compounds reported in the high zinc region needs revision.

2. Intermetallic Phases

Veleckis¹⁴⁵ established the sequence of intermetallic phases in the lanthanum-zinc system by using the recording-effusion method. Compounds with the following stoichiometry and structures were found:

Compound	Crystal Class	Lattice Parameters, Å	References
LaZn ₁₃	Cubic	a = 12.08	129
LaZn ₁₁	Tetragonal	a = 10.68 c = 6.87	128
La ₂ Zn ₁₇	Hexagonal	-	129
LaZn _{7.3}	-	-	-
LaZn _{5.3}	Hexagonal	a = 5.427 c = 4.225	103
LaZn ₄	-	-	-
LaZn ₂	Orthorhombic	a = 4.70 b = 7.74 c = 7.75	124
LaZn	Cubic	a = 3.759	63

B. Solubility Data

The solubility of lanthanum in liquid zinc was determined by Schramm¹³³ by thermal analysis and by Nathans and Anderson¹⁰¹ by analysis of filtered samples. These data are shown in Fig. 16. The measurements covered the range of 500-960°C. In the region of 850°C, a peritectic reaction occurs; accordingly, the direct measurements were represented by the following two sets of empirical equations, one above and one below 850°C:

$t < 850^{\circ}\text{C}$

$$\log (\text{a/o La}) = 8.284 - 8752T^{-1};$$

$$\log (\text{w/o La}) = 8.573 - 8718T^{-1};$$

 $t > 850^{\circ}\text{C}$

$$\log (\text{a/o La}) = 5.348 - 5402T^{-1};$$

$$\log (\text{w/o La}) = 5.418 - 5133T^{-1}.$$

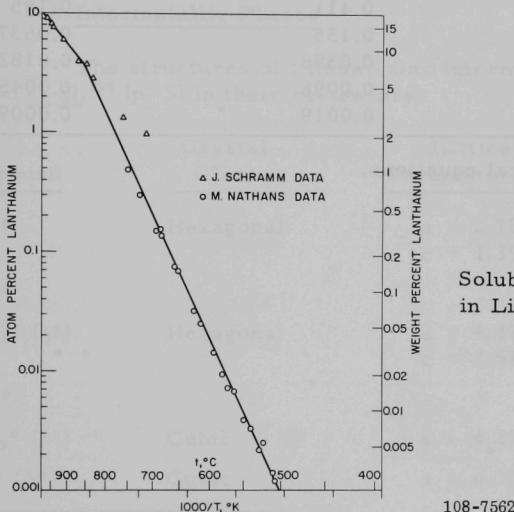


Fig. 16

Solubility of Lanthanum
in Liquid Zinc

Experimental data are given in Table XXXVI, and calculated values of the solubility at 50°C intervals are given in Table XXXVII.

TABLE XXXVI. Solubility of Lanthanum in Liquid Zinc: Experimental Data

$t, ^\circ\text{C}$	$\frac{1000}{T, ^\circ\text{K}}$	Lanthanum, w/o	Lanthanum, a/o	$t, ^\circ\text{C}$	$\frac{1000}{T, ^\circ\text{K}}$	Lanthanum, w/o	Lanthanum, a/o
962 ^a	0.810	19.1	10.0	750 ^b	0.977	0.93	0.47
960 ^a	0.811	18.0	9.31	749 ^b	0.978	1.07	0.50
959 ^a	0.812	17.5	9.10	714 ^a	1.013	2.1	0.99
947 ^a	0.820	16.0	8.19	686 ^b	1.043	0.327	0.154
940 ^a	0.824	15.0	7.62	683 ^b	1.046	0.29	0.137
912 ^a	0.844	12.0	5.99	653 ^b	1.080	0.147	0.069
870 ^a	0.875	8.0	3.93	614 ^b	1.127	0.0542	0.025
848 ^a	0.892	7.7	3.75	540 ^b	1.230	0.0070	0.0033
832 ^a	0.905	5.9	2.85	498 ^b	1.297	0.0022	0.00104
762 ^a	0.966	2.8	1.33	498 ^b	1.297	0.0020	0.00094
752 ^b	0.975	1.07	0.50				

^aJ. Schramm.¹³⁴^bM. W. Nathans and K. E. Anderson.¹⁰¹

TABLE XXXVII. Solubility of Lanthanum in Liquid Zinc: Calculated^a

t, °C	$\frac{1000}{T, ^\circ K}$	Lanthanum, w/o	Lanthanum, a/o
950	0.818	16.6	8.53
900	0.852	11.0	5.23
850	0.890	6.47	3.10
800	0.932	2.81	1.35
750	0.977	1.13	0.538
700	1.028	0.411	0.195
650	1.083	0.135	0.0637
600	1.145	0.0388	0.0182
550	1.215	0.0096	0.0045
500	1.293	0.0019	0.00092

^aCalculated from empirical equations.

LITHIUM-ZINC

A. Phase Information1. Phase Diagram

The phase diagram for the lithium-zinc system is reported in Hansen and Anderko⁵⁰ (p. 906). A complex sequence of intermediate phases of wide composition ranges is shown.

2. Intermetallic Phases

The structures of lithium-zinc intermetallic phases given by Stanton et al.¹³⁹ (p. 5) in their review are:

<u>Compound</u>	<u>Crystal Class</u>	<u>Lattice Parameters, Å</u>	<u>References</u>
LiZn ₉ *	Hexagonal	a = 2.78 c = 4.39	152
LiZn ₄ *			11
Li ₃ Zn ₈ * (γ')	Hexagonal	a = 4.371 c = 2.515	45, 152
LiZn ₂ *			45, 152
Li ₂ Zn ₃ * (δ')	Cubic	a = 4.27	11, 45
LiZn* (δ'')	Cubic	a = 6.22	11, 152, 153

*Approximate composition, not line compounds.

B. Solubility Data

Grube and Vosskühler⁴⁵ used thermal analysis to determine the solubility of lithium in liquid zinc over the range of 418-520°C. These data are plotted in Fig. 17. Several different intermediate phases are in equilibrium with the saturated solution over this temperature range. The direct measurements may be represented by the following empirical equations over the range of 400-520°C:

$$\log (a/o \text{ Li}) = 6.813 - 4160T^{-1};$$

$$\log (a/o \text{ Li}) = 6.951 - 4921T^{-1}.$$

Experimental data are given in Table XXXVIII and calculated values of the solubility at 20°C intervals are given in Table XXXIX.

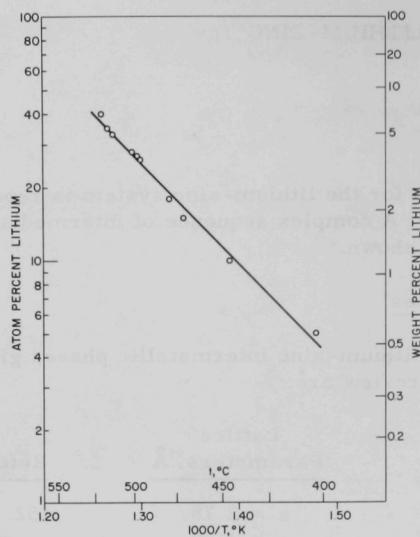


Fig. 17
Solubility of Lithium
in Liquid Zinc

108-7557

TABLE XXXVIII. Solubility of
Lithium in Liquid Zinc:
Experimental Data^a

$t, ^\circ C$	$1000/T, ^\circ K$	Lithium, w/o	Lithium, a/o
520	1.261	6.61	40
516	1.267	5.40	35
513	1.272	4.97	33
501	1.292	3.96	28
498	1.297	3.78	27
496	1.300	3.59	26
479	1.330	2.28	18
471	1.344	1.84	15
446	1.391	1.17	10
403	1.479	0.56	5

^aG. Grube and H. Vosskühler.⁴⁵

TABLE XXXIX. Solubility of
Lithium in Liquid Zinc:
Calculated^a

$t, ^\circ C$	$1000/T, ^\circ K$	Lithium, w/o	Lithium, a/o
520	1.261	5.57	36.9
500	1.293	3.85	27.0
480	1.328	2.61	19.5
460	1.364	1.73	13.7
440	1.402	1.12	9.80
420	1.443	0.71	6.46
400	1.486	0.44	4.28

^aCalculated from empirical
equations.

MAGNESIUM-ZINC

A. Phase Information1. Phase Diagram

The phase diagram for the magnesium-zinc system is reported by Hansen and Anderko⁵⁰ (p. 928) for the entire range of composition. The controversial range (30-66.7 a/o zinc) is discussed by Hansen and Anderko⁵⁰ (p. 930) in some detail. The intermediate phases apparently have narrow homogeneity ranges.

2. Intermetallic Phases

The structures of magnesium-zinc intermetallic phases given by Stanton *et al.*¹³⁹ (p. 7) in their review are:

Compound	Crystal Class	Lattice Parameters, Å	References
Mg ₂ Zn ₁₁	Cubic	a = 8.552	77, 82, 95, 127, 141
MgZn ₂	Hexagonal	a = 5.16 c = 8.50	29, 40, 77
Mg ₂ Zn ₃			29, 77
MgZn	Orthorhombic	a = 8.60 b = 9.24 c = 5.34	29, 77, 95, 141
Mg ₇ Zn ₃			29, 78, 77

B. Solubility Data

The solubility of magnesium in liquid zinc was determined by Hume-Rothery and Rounsefell⁶² over the range of 370-590°C. Two equilibrium solid phases are involved: 367-383°C for Mg₂Zn₁₁ and 383-590°C for MgZn₂. Their measurements are plotted in Fig. 18. The direct measurements may be represented by the following empirical equations over the range of 370-590°C:

$$\log (\text{a/o Mg}) = 3.050 - 1382T^{-1};$$

$$\log (\text{w/o Mg}) = 3.104 - 1678T^{-1}.$$

Experimental data are given in Table XL and calculated values of the solubility at 25°C temperature intervals are given in Table XLI.

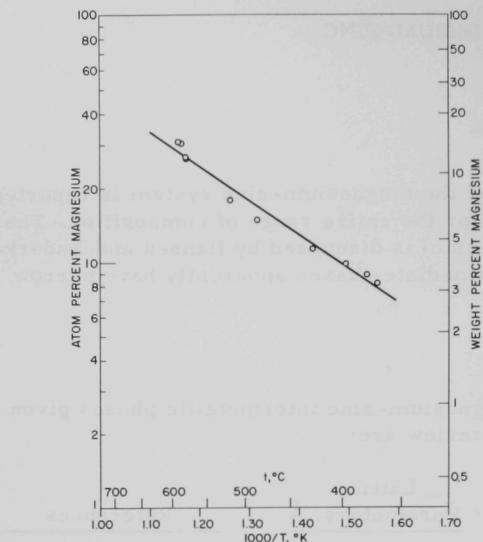


Fig. 18

Solubility of Magnesium
in Liquid Zinc

108-7564

TABLE XL. Solubility of Magnesium
in Liquid Zinc: Experimental Data^a

$t, ^\circ\text{C}$	$\frac{1000}{T, ^\circ\text{K}}$	Magnesium, w/o	Magnesium, a/o
590	1.159	16.7	31.0
585	1.165	16.3	30.5
580	1.172	13.6	26.8
579	1.174	13.3	26.3
519	1.262	8.1	17.9
487	1.316	6.5	14.9
427	1.428	4.8	11.4
396	1.494	4.1	9.9
378	1.536	3.6	8.9
369	1.557	3.3	8.25

^aW. Hume-Rothery and E. Rounsefell.⁶²

TABLE XLI. Solubility of Magnesium
in Liquid Zinc: Calculated^a

$t, ^\circ\text{C}$	$\frac{1000}{T, ^\circ\text{K}}$	Magnesium, w/o	Magnesium, a/o
590	1.158	14.5	28.1
575	1.179	13.4	26.3
550	1.215	11.6	23.4
525	1.253	10.0	20.8
500	1.293	8.58	18.3
475	1.337	7.26	15.9
450	1.383	6.07	13.8
425	1.432	5.02	11.8
400	1.486	4.08	9.92
375	1.543	3.27	8.27

^aCalculated from empirical equations.

MANGANESE-ZINC

A. Phase Information1. Phase Diagram

The phase diagram for the manganese-zinc system is reported by Hansen and Anderko⁵⁰ (p. 963) for the entire range of composition and also for the zinc-rich portion (p. 964). A complex sequence of intermediate phases of wide composition range is shown.

2. Intermetallic Phases

The structures of manganese-zinc intermetallic phases given by Stanton *et al.*¹³⁹ (p. 12) in their review are:

Compound	Crystal Class	Lattice Parameters, Å	References
MnZn ₁₃ * (ζ)	Monoclinic	a = 13.67 b = 7.62 c = 5.07	132
MnZn ₉ * (δ ₁)	Hexagonal	a = 12.8 c = 57.5	132
Mn ₅ Zn ₂₁ * (γ)	Cubic	a = 9.14	117, 132
MnZn ₃ *	Cubic	a = 3.849	132
MnZn*	Cubic	a = 3.060	120, 132
MnZn*	Hexagonal		120, 132

*Approximate composition, not line compounds.

B. Solubility Data

Schramm¹³² and Edmunds³⁴ determined the solubility of manganese in liquid zinc by thermal analysis. Their data, covering the range of 440-800°C, are plotted in Fig. 19. The ε phase, which has a wide homogeneity range, is the equilibrium solid phase. Their measurements may be represented by the following empirical equations over the range of 420-800°C:

$$\log (a/o \text{ Mn}) = 3.536 - 2142T^{-1};$$

$$\log (w/o \text{ Mn}) = 3.529 - 2193T^{-1}.$$

Experimental data are given in Table XLII, and calculated values of the solubility at 50°C intervals are given in Table XLIII.

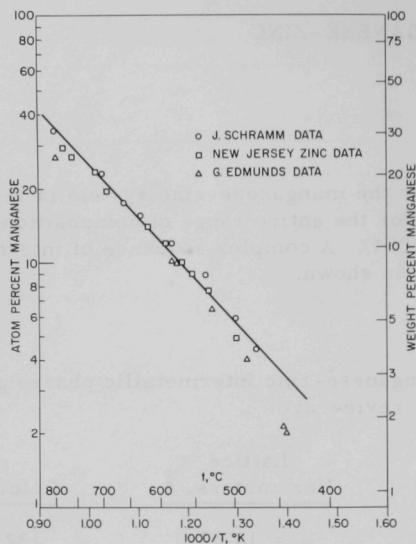


Fig. 19

Solubility of Manganese
in Liquid Zinc

TABLE XLII. Solubility of Manganese in Liquid Zinc: Experimental Data

$t, ^\circ\text{C}$	$1000/T, \text{K}^{-1}$	Manganese, w/o	Manganese, a/o
800 ^a	0.932	30.7	34.5
798 ^b	0.934	23.5	26.8
780 ^b	0.950	26.0	29.5
760 ^b	0.968	23.7	27.0
712 ^b	1.015	20.5	23.5
700 ^a	1.028	20.1	23.0
690 ^b	1.038	16.9	19.5
660 ^a	1.072	15.1	17.5
632 ^a	1.105	13.3	15.5
611 ^b	1.131	12.0	14.0
592 ^b	1.156	10.3	12.0
582 ^a	1.169	10.2	11.9
582 ^b	1.169	8.61	10.1
576 ^b	1.178	8.45	9.9
567 ^b	1.190	8.5	10.0
553 ^b	1.210	7.7	9.0
535 ^a	1.237	7.6	8.9
532 ^b	1.242	6.5	7.7
527 ^b	1.250	5.47	6.45
498 ^a	1.297	5.04	5.95
498 ^b	1.297	4.19	4.95
485 ^b	1.319	3.40	4.03
475 ^a	1.337	3.76	4.45
446 ^b	1.391	1.80	2.14
442 ^b	1.398	1.69	2.01

^aJ. Schramm.¹³²^bG. Edmunds.³⁴

TABLE XLIII. Solubility of Manganese in Liquid Zinc: Calculated^a

t, °C	$\frac{1000}{T, ^\circ K}$	Manganese, w/o	Manganese, a/o
800	0.932	31.3	35.6
750	0.977	25.8	28.4
700	1.028	19.1	22.0
650	1.083	14.4	16.7
600	1.145	10.47	12.21
550	1.215	7.30	8.59
500	1.293	4.90	5.81
450	1.383	3.08	3.70

^aCalculated from empirical equations.TABLE XLIV. Solubility of Molybdenum in Liquid Zinc: Calculated^a

t, °C	$\frac{1000}{T, ^\circ K}$	Molybdenum, w/o	Molybdenum, a/o
420	1.0607	0.00337	
430	1.0522	0.00390	
440	1.0432	0.00445	
450	1.0339	0.00500	
460	1.0244	0.00560	
470	1.0147	0.00742	
480	1.0047	0.00863	
490	0.9945	0.00988	
500	0.9839	0.01114	
510	0.9731	0.01231	
520	0.9621	0.01341	
530	0.9509	0.01445	
540	0.9395	0.01542	
550	0.9280	0.01636	

^aCalculated from empirical equations.

MOLYBDENUM-ZINC

A. Phase Information1. Phase Diagram

No data are available for the phase diagram for the molybdenum-zinc system.

2. Intermetallic Phases

The structures of the intermetallic phases have not been reported.

B. Solubility Data

The solubility of molybdenum in liquid zinc has been determined by Martin, Knighton, and Feder.⁹⁴ Their data cover the range of 422-730°C and are reported in Fig. 20. The direct measurements may be represented by the following two sets of empirical equations over the ranges 420-550°C and 550-725°C:

420-550°C

$$a/o \text{ Mo} = 0.0150; \quad w/o \text{ Mo} = 0.0220.$$

550-725°C

$$\log (a/o \text{ Mo}) = 2.493 - 3560T^{-1};$$

$$\log (w/o \text{ Mo}) = 3.900 - 4556T^{-1}.$$

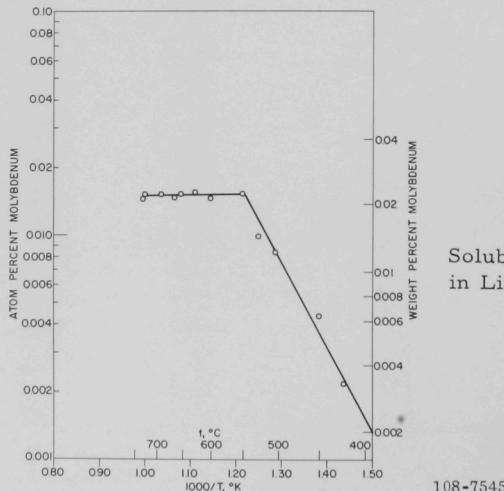


Fig. 20
Solubility of Molybdenum
in Liquid Zinc

One or more intermetallic compounds are in equilibrium with the saturated solution over the range of 420 to 550°C; above 550°C, the equilibrium solid phase is pure molybdenum.

Experimental data are given in Table XLIV, and calculated values of the solubility at 10°C intervals are given in Table XLV.

TABLE XLIV. Solubility of Molybdenum in Liquid Zinc: Experimental Data^a

t, °C	T, °K	1000 Molybdenum, w/o	Molybdenum, a/o
730.5	0.996	0.0213	0.0145
726.9	1.000	0.0224	0.0152
690.3	1.038	0.0224	0.0152
664.3	1.066	0.0216	0.0147
652.5	1.080	0.0224	0.0152
635.3	1.101	0.0227	0.0155
593.3	1.154	0.0213	0.0145
550.4	1.214	0.0225	0.0153
527.1	1.250	0.0145	0.00988
502.4	1.289	0.0122	0.00830
450.7	1.381	0.00636	0.00433
422.4	1.438	0.00314	0.00214

^aA. E. Martin, J. B. Knighton and H. M. Feder.⁹⁴

TABLE XLV. Solubility of Molybdenum in Liquid Zinc: Calculated^a

t, °C	T, °K	1000 Molybdenum, w/o	Molybdenum, a/o
420	1.443	0.00335	0.00228
430	1.422	0.00390	0.00269
440	1.402	0.00465	0.00317
450	1.383	0.00550	0.00372
460	1.364	0.00640	0.00434
470	1.346	0.00742	0.00504
480	1.328	0.00863	0.00584
490	1.310	0.00988	0.00673
500	1.293	0.01148	0.00774
510	1.278	0.0131	0.00886
520	1.261	0.0149	0.0101
530	1.245	0.0170	0.0115
540	1.230	0.0192	0.0130
550	1.215	0.0216	0.0147

^aCalculated from empirical equations.

SODIUM-ZINC

A. Phase Information1. Phase Diagram

The phase diagram for the sodium-zinc system is given in Hansen and Anderko⁵⁰ (p. 1010). The single compound NaZn_{13} decomposes into two immiscible liquid layers at about 557°C.

2. Intermetallic Phase

The structure of the sodium-zinc intermetallic phase given by Stanton *et al.*¹³⁹ (p. 5) in their review is:

Compound	Crystal Class	Lattice Parameter, Å	References
NaZn_{13}	Cubic	$a = 12.2836$	69, 81, 136, 154

B. Solubility Data

Anderson and Bartos⁵ determined the solubility of sodium in liquid zinc by analysis of filtered samples. Their measurements, which covered the range of 430-587°C, are plotted in Fig. 21. The direct measurements

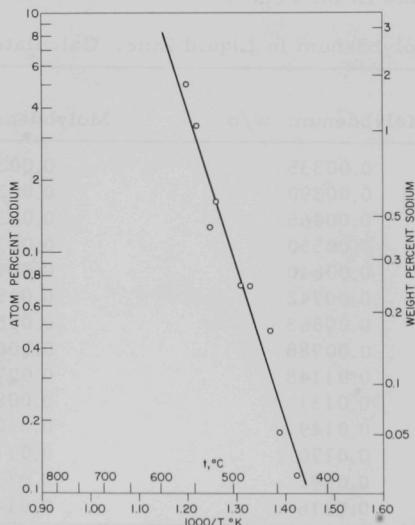


Fig. 21
Solubility of Sodium
in Liquid Zinc

may be represented by the following empirical equations in the range of 425-560°C:

$$\log (a/o \text{ Na}) = 8.208 - 6364T^{-1};$$

$$\log (w/o \text{ Na}) = 7.840 - 6426T^{-1}.$$

Experimental data are given in Table XLVI, and calculated values of the solubility of 25°C intervals are given in Table XLVII.

TABLE XLVI. Solubility of Sodium in Liquid Zinc: Experimental Data^a

t, °C	¹⁰⁰⁰		Sodium, a/o
	T, °K	Sodium, w/o	
562	1.197	1.84	5.05
548	1.218	1.21	3.36
530	1.245	0.455	1.28
522	1.258	0.580	1.63
491	1.309	0.258	0.730
480	1.328	0.257	0.727
457	1.370	0.171	0.484
447	1.389	0.0630	0.179
430	1.422	0.0418	0.119

TABLE XLVII. Solubility of Sodium in Liquid Zinc: Calculated^a

t, °C	¹⁰⁰⁰		Sodium, a/o
	T, °K	Sodium, w/o	
550	1.215	1.08	3.00
525	1.253	0.615	1.72
500	1.293	0.338	0.949
475	1.337	0.178	0.504
450	1.383	0.090	0.256
425	1.432	0.043	0.124

^aCalculated from empirical equations.

^aK. E. Anderson and J. Bartos.⁵

NIOBIUM-ZINC

A. Phase Information1. Phase Diagram

The phase diagram has been reported by Meussner and Goode.⁹⁷ A sequence of intermediate phases of narrow composition range is reported.

2. Intermetallic Phases

The phases reported by Meussner and Goode are:

Compound	Crystal Type	Lattice Parameters, Å
NbZn ₁₅	Not determined	
NbZn ₇	Not determined	
NbZn ₃	Cubic, Ll ₂ (AuCu ₃ type)	
NbZn ₂	Hexagonal, C36	$a_0 = 5.05, c_0 = 16.32$
NbZn	Hexagonal	$a_0 = 5.06, c_0 = 26.43$
NbZn	Not determined	

B. Solubility Data

Martin, Knighton, and Feder⁹⁴ analyzed filtered samples to determine the solubility of niobium in liquid zinc. These measurements cover the range of 427 to 750°C, and the data are shown in Fig. 22. The direct

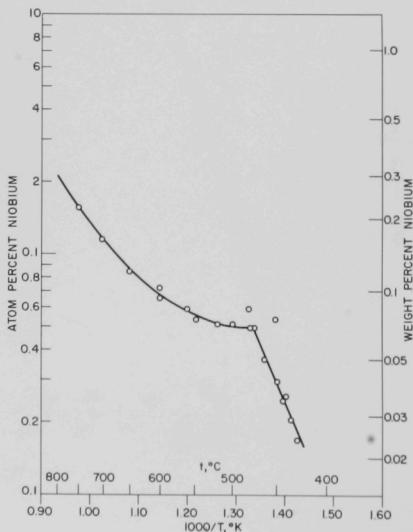


Fig. 22

Solubility of Niobium
in Liquid Zinc

measurements may be represented by two sets of empirical equations over the ranges of 419-478°C and 478-750°C. The solid phase in equilibrium with the solution over the 419-478°C range is probably NbZn₁₅ below 429°C and NbZn₇ above 429°C. From 478 to 750°C, the equilibrium phase is NbZn₃. The empirical equations are as follows:

419-478°C

$$\log (a/o \text{Nb}) = 5.029 - 4749T^{-1};$$

$$\log (w/o \text{Nb}) = 5.182 - 4749T^{-1}.$$

478-750°C

$$\log (a/o \text{Nb}) = 5.924 - 10938T^{-1} + 4.142 \times 10^6 T^{-2};$$

$$\log (w/o \text{Nb}) = 6.077 - 10938T^{-1} + 4.142 \times 10^6 T^{-2}.$$

Experimental data are given in Table XLVIII, and calculated values of the solubility at 25°C and 50°C intervals in Table XLIX.

TABLE XLVIII. Solubility of Niobium in Liquid Zinc: Experimental Data^a

t, °C	T, °K	1000	Niobium, w/o	Niobium, a/o
750.7	0.977	0.222	0.156	
702.8	1.025	0.163	0.115	
651.3	1.082	0.120	0.0844	
601.1	1.144	0.103	0.0725	
600.9	1.144	0.0931	0.0655	
560.6	1.200	0.0841	0.0592	
547.3	1.219	0.0759	0.0534	
518.8	1.263	0.0727	0.0512	
599.8	1.294	0.0728	0.0513	
480.8	1.326	0.0839	0.0590	
478.9	1.330	0.0702	0.0494	
474.4	1.338	0.0698	0.0491	
462.8	1.359	0.0520	0.0366	
451.0	1.381	0.0765	0.0538	
449.6	1.384	0.0420	0.0296	
442.4	1.397	0.0348	0.0245	
439.4	1.403	0.0367	0.0257	
433.9	1.414	0.0290	0.0204	
427.9	1.426	0.0240	0.0169	

TABLE XLIX. Solubility of Niobium in Liquid Zinc: Calculated^a

t, °C	T, °K	1000	Niobium, w/o	Niobium, a/o
800	0.932	0.302	0.213	
750	0.977	0.220	0.155	
700	1.028	0.162	0.114	
650	1.083	0.123	0.0862	
600	1.145	0.0961	0.0676	
550	1.215	0.0797	0.0561	
500	1.293	0.0722	0.0508	
475	1.337	0.0687	0.0480	
450	1.383	0.0412	0.0290	
425	1.432	0.0240	0.0168	

^aCalculated from empirical equations.

^aA. E. Martin, J. B. Knighton, and H. M. Feder.⁹⁴

NEODYMIUM-ZINC

A. Phase Information1. Phase Diagram

No data are available on the phase diagram of this system.

2. Intermetallic Phases

Veleckis¹⁴⁵ used the recording effusion balance to study the neodymium-zinc system. The following intermetallic phases were found:

Compound	Crystal Class	Lattice Parameters, Å	References
NdZn_{11}	Tetragonal		
NdZn_{17}	Hexagonal		
$\text{NdZn}_{6.5}$			
$\text{NdZn}_{4.3}$			
$\text{NdZn}_{3.6}$			
NdZn_3			
NdZn_2	Orthorhombic	$a = 4.597$ $b = 7.403$ $c = 7.881$	124
NdZn	Cubic	3.657	19

B. Solubility Data

Johnson and Anderson⁶⁵ analyzed filtered samples to determine the solubility of neodymium in zinc. These measurements cover the range of 426-713°C, and the data are shown in Fig. 23. The direct measurements

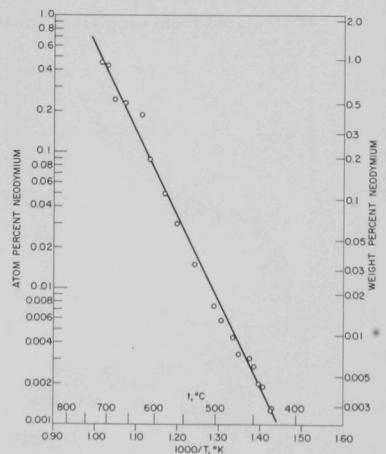


Fig. 23
Solubility of Neodymium
in Liquid Zinc

may be represented by the following empirical equations over the range of 425-750°C:

$$\log (a/o \text{ Nd}) = 6.071 - 6289T^{-1};$$

$$\log (w/o \text{ Nd}) = 6.412 - 6287T^{-1}.$$

Experimental data are given in Table L, and calculated values of the solubility at 50°C intervals are given in Table LI.

TABLE L. Solubility of Neodymium in Liquid Zinc: Experimental Data^a

t, °C	<u>1000</u> T, °K	Neodymium, w/o	Neodymium, a/o
713	1.014	0.989	0.450
698	1.030	0.958	0.432
682	1.047	0.532	0.242
659	1.073	0.496	0.223
658	1.074	0.501	0.228
625	1.113	0.415	0.189
609	1.134	0.195	0.088
582	1.169	0.108	0.0490
561	1.199	0.0655	0.0297
532	1.242	0.033	0.0150
503	1.288	0.0163	0.00738
493	1.305	0.0127	0.00575
476	1.335	0.00953	0.00432
468	1.349	0.00726	0.00329
454	1.375	0.00690	0.00313
449	1.385	0.00588	0.00267
443	1.396	0.00436	0.00198
437	1.408	0.00419	0.00190
428	1.426	0.00281	0.00127
426	1.430	0.00290	0.00131

^aI. Johnson and K. E. Anderson.⁶⁵

TABLE LI. Solubility of Neodymium in Liquid Zinc: Calculated^a

t, °C	<u>1000</u> T, °K	Neodymium, w/o	Neodymium, a/o
750	0.977	1.851	0.840
700	1.028	0.895	0.406
650	1.083	0.400	0.181
600	1.145	0.163	0.0739
550	1.215	0.0595	0.0270
500	1.293	0.0191	0.00865
450	1.383	0.00520	0.00236
425	1.432	0.00255	0.00115

^aCalculated from empirical equations.

NICKE L-ZINC

A. Phase Information1. Phase Diagram

The phase diagram for the nickel-zinc system is reported in Hansen and Anderko⁵⁰ (p. 1060). A complex sequence of intermediate phases of wide composition range is shown.

2. Intermetallic Phases

The structures of the nickel-zinc intermetallic phases given by Stanton *et al.*¹³⁹ (pp. 13-14) in their review are:

Compound*	Crystal Class	Lattice Parameters, Å	References
Ni ₄ Zn ₃₁ (γ_1)	Hexagonal	a = 8.855 c = 14.58	131
Ni ₅ Zn ₂₁ (γ)	Cubic	a = 8.91	37, 131
NiZn (β_1)	Tetragonal	a = 2.743 c = 3.195	55, 56
NiZn (β)	Cubic	a = 2.914	55, 56

*All phases have an appreciable range of composition.

B. Solubility Data

Heike, Schramm, and Vaupel⁵⁵ determined the solubility of nickel in liquid zinc by thermal analysis. These measurements cover the range of 485-880°C and are given in Fig. 24. The γ phase is the equilibrium solid over this temperature range. The direct measurements may be represented by the following empirical equations in the range of 450-850°C:

$$\log (a/o \text{ Ni}) = 4.040 - 3165T^{-1};$$

$$\log (w/o \text{ Ni}) = 4.009 - 3173T^{-1}.$$

Experimental data are given in Table LII, and calculated values of the solubility at 50°C intervals in Table LIII.

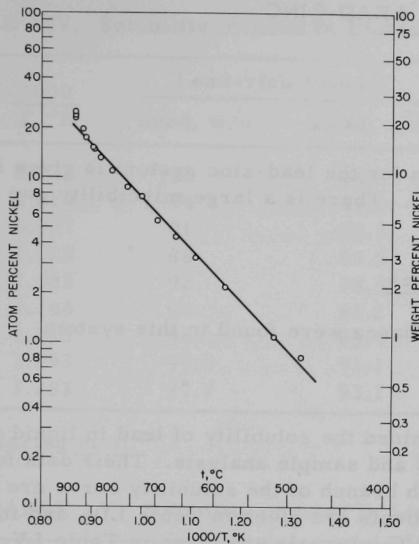


Fig. 24

Solubility of Nickel
in Liquid Zinc

108-7559

TABLE LII. Solubility of Nickel in
Liquid Zinc: Experimental Data^a

$t, {}^\circ\text{C}$	T, K	Nickel, w/o	Nickel, a/o
880.9	0.867	23	25.0
880.5	0.867	22	23.9
879	0.868	21	22.8
862	0.881	18	19.7
854	0.887	16	17.5
837	0.901	14	15.3
835	0.902	13.5	14.8
818	0.917	12	13.2
791	0.940	10	11.0
760	0.968	8	8.8
732	0.995	7	7.7
696	1.032	5	5.5
664	1.067	4	4.4
630	1.107	3	3.3
585	1.165	2	2.2
518	1.264	1	1.1
485	1.319	0.75	0.83

^aW. Heike, J. Schramm, and
O. Vaupel.⁵⁵

TABLE LIII. Solubility of Nickel
in Liquid Zinc: Calculated^a

$t, {}^\circ\text{C}$	T, K	Nickel, w/o	Nickel, a/o
850	0.890	15.3	16.7
800	0.932	11.3	12.4
750	0.977	8.08	8.86
700	1.028	5.60	6.15
650	1.083	3.73	4.10
600	1.145	2.37	2.61
550	1.215	1.42	1.57
500	1.293	0.802	0.886
450	1.383	0.417	0.462

^aCalculated from empirical equations.

LEAD-ZINC

A. Phase Information1. Phase Diagram

The phase diagram for the lead-zinc system is given in Hansen and Anderko⁵⁰ (p. 1119). There is a large miscibility gap in the liquid state.

2. Intermetallic Phases

No intermetallic phases were found in this system.

B. Solubility Data

Waring *et al.*¹⁴⁷ determined the solubility of lead in liquid zinc by separation of the liquid layers and sample analysis. Their data for the lead-rich branch and zinc-rich branch of the solubility curve are given in Fig. 25. The direct measurements are given in Table LIV, and interpolated values of solubility at 25°C intervals are given in Table LV.

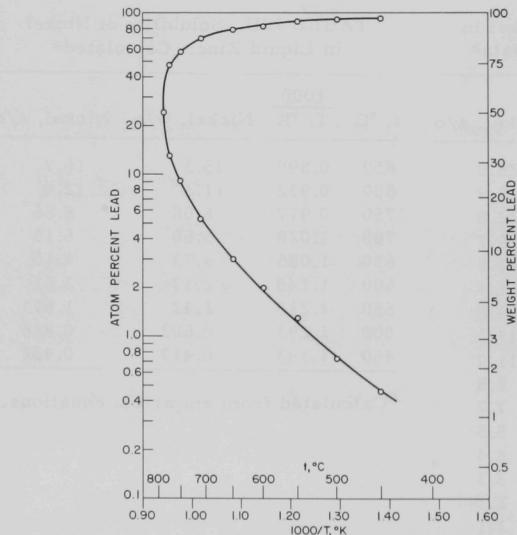


Fig. 25
Solubility of Lead
in Liquid Zinc

TABLE LIV. Solubility of Lead in Liquid Zinc: Experimental Data^a

t, °C	$\frac{1000}{T, ^\circ K}$	Lead-rich Branch		Zinc-rich Branch	
		Lead, w/o	Lead, a/o	Lead, w/o	Lead, a/o
790	0.941	50	24	50	24
775	0.954	74	47.3	32	13.0
750	0.977	81	57.3	24	9.1
700	1.028	88	69.9	15	5.3
650	1.083	92	78.5	9	3.0
600	1.145	94	83.2	6	2.0
550	1.215	96	88.4	4	1.3
500	1.293	97.0	91.1	2.3	0.73
450	1.383	97.7	93.1	1.44	0.46

^aR. K. Waring et al.¹⁴⁷TABLE LV. Solubility of Lead in Liquid Zinc: Estimated^a

t, °C	$\frac{1000}{T, ^\circ K}$	Lead-rich Branch		Zinc-rich Branch	
		Lead, w/o	Lead, a/o	Lead, w/o	Lead, a/o
790	0.941	50	24	50.0	24.0
775	0.954	74	47	35.1	13.1
750	0.977	81	57	24.1	9.1
725	1.002	86	65	18.2	6.55
700	1.028	89	71	14.0	4.9
675	1.055	91	76	11.1	3.8
650	1.083	92	79	8.9	3.0
625	1.113	94	82	7.2	2.4
600	1.145	95	85	5.8	1.92
575	1.179	96	87	4.7	1.53
550	1.215	96	89	3.7	1.21
525	1.253	97	91	3.0	0.96
500	1.293	97	92	2.4	0.76
475	1.337	98	93	1.88	0.60
450	1.393	98	93	1.47	0.47

^aObtained from Fig. 25.

PALLADIUM-ZINC

A. Phase Information

1. Phase Diagram

The phase diagram for the palladium-zinc system is reported in Hansen and Anderko⁵⁰ (pp. 1131 and 1132). A complex sequence of intermediate phases of wide homogeneity range is shown.

2. Intermetallic Phases

The structures of palladium-zinc intermetallic phases given by Stanton *et al.*¹³⁹ (pp. 14-15) in their review are:

Compound*	Crystal Class	Lattice Parameters, Å	References
PdZn (β_1)	Cubic	a = 9.108	36, 79, 106, 108
PdZn ₁₂ (η)	Hexagonal		
Pd ₂ Zn ₃	Cubic	a = 3.04	79, 106
PdZn (β_1)	Tetragonal	a = 4.09 c = 3.34	79, 104, 106
Pd ₂ Zn (β'')	Cubic	a = 3.05	79, 106

*All phases have a range of composition.

B. Solubility Data

The solubility of palladium in liquid zinc has been determined by Nowotny, Bauer, and Stempfl¹⁰⁶ by thermal analysis, and by Martin, Knighton and Feder⁹⁴ by analysis of filtered samples. These data cover the range of 439-890°C and are shown in Fig. 26. The γ phase is in equilibrium with the saturated solution over this temperature range. The direct measurements may be represented by the following empirical equations over the range of 425-900°C:

$$\log (a/o \text{ Pd}) = 4.061 - 3242T^{-1};$$

$$\log (w/o \text{ Pd}) = 4.174 - 3166T^{-1}.$$

Experimental data are given in Table LVI, and calculated values of the solubility at 50°C intervals in Table LVII.

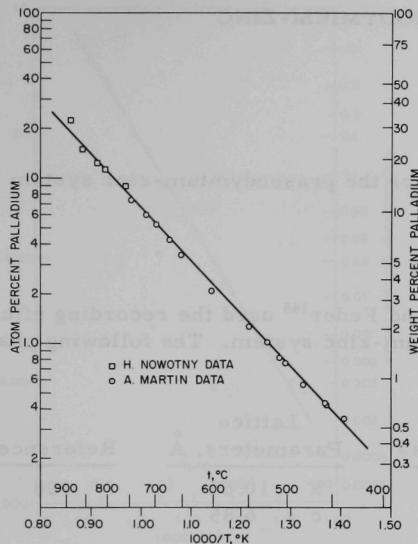


Fig. 26

Solubility of Palladium
in Liquid Zinc

108-7561

TABLE LVI. Solubility of Palladium
in Liquid Zinc: Experimental Data

t, °C	1000 T, °K	Palladium, w/o	Palladium, a/o
892 ^a	0.858	32.1	22.5
860 ^a	0.883	22.4	15.0
823 ^a	0.912	18.9	12.5
805 ^a	0.928	17.4	11.4
760 ^a	0.968	13.9	9.0
749.7 ^b	0.978	11.6	7.44
718.0 ^b	1.009	9.47	6.02
699.0 ^b	1.029	8.34	5.28
674.0 ^b	1.056	6.78	4.27
654.8 ^b	1.078	5.53	3.46
604.2 ^b	1.140	3.39	2.10
550.0 ^b	1.215	2.07	1.28
525.3 ^b	1.252	1.67	1.03
510.0 ^b	1.277	1.35	0.832
503.2 ^b	1.288	1.24	0.763
482.5 ^b	1.323	0.919	0.565
457.9 ^b	1.368	0.712	0.438
456.2 ^b	1.371	0.686	0.421
438.8 ^b	1.406	0.571	0.351

^aH. Nowotny, E. Bauer, and A. Stempfl,¹⁰⁶^bA. E. Martin, J. B. Knighton, and H. M. Feder.⁹⁴

TABLE LVII. Solubility of Palladium
in Liquid Zinc: Calculated^a

t, °C	1000 T, °K	Palladium, w/o	Palladium, a/o
900	0.852	29.9	19.8
850	0.890	22.7	15.0
800	0.932	16.7	11.0
750	0.977	12.0	7.80
700	1.028	8.33	5.36
650	1.083	5.55	3.54
600	1.145	3.53	2.23
550	1.215	2.13	1.33
500	1.293	1.20	0.738
450	1.383	0.625	0.378
425	1.432	0.444	0.274

^aCalculated from empirical equations.

PRASEODYMIUM-ZINC

A. Phase Information1. Phase Diagram

The phase diagram for the praseodymium-zinc system has not been determined.

2. Intermetallic Phases

Veleckis, Johnson, and Feder¹⁴⁵ used the recording effusion balance to study the praseodymium-zinc system. The following phases were found:

Compound	Crystal Class	Lattice Parameters, Å	References
PrZn ₁₁	Tetragonal	a = 10.65 c = 6.85	128
Pr ₂ Zn ₁₇	Hexagonal		
PrZn ₇			
PrZn _{5.3}	Hexagonal		
PrZn _{4.3}			
PrZn _{3.6}			
PrZn ₃			
PrZn ₂	Orthorhombic	a = 4.60 b = 7.49 c = 7.45	124
PrZn	Cubic	a = 3.678	63

B. Solubility Data

Johnson and Anderson⁶⁶ determined the solubility of praseodymium in liquid zinc by analysis of filtered samples. Their measurements cover the range of 425-725°C, and the data are plotted in Fig. 27. The direct measurements may be represented by the following empirical equations over the range of 425-750°C:

$$\log (a/o \text{ Pr}) = 6.268 - 6591T^{-1};$$

$$\log (w/o \text{ Pr}) = 6.593 - 6584T^{-1}.$$

Experimental data are given in Table LVIII and calculated values of the solubility at 50°C intervals are given in Table LIX.

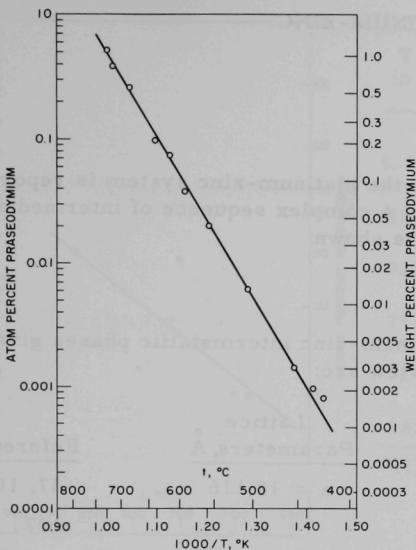


Fig. 27

Solubility of Praseodymium
in Liquid Zinc

108-7547

TABLE LVIII. Solubility of Praseodymium
in Liquid Zinc: Experimental Data^a

$t, ^\circ\text{C}$	$\frac{1000}{T, ^\circ\text{K}}$	Praseodymium, w/o	Praseodymium, a/o
725	1.002	1.11	0.518
713	1.014	0.823	0.383
681	1.048	0.554	0.258
637	1.099	0.208	0.0966
614	1.127	0.160	0.0742
592	1.156	0.081	0.0376
557	1.205	0.0424	0.0197
507	1.282	0.0132	0.00612
454	1.375	0.00306	0.00142
434	1.414	0.00207	0.00095
425	1.432	0.00172	0.00080

^aI. Johnson and K. E. Anderson.⁶⁶

TABLE LIX. Solubility of Praseodymium
in Liquid Zinc: Calculated^a

$t, ^\circ\text{C}$	$\frac{1000}{T, ^\circ\text{K}}$	Praseodymium, w/o	Praseodymium, a/o
750	0.977	1.52	0.706
700	1.028	0.685	0.318
650	1.083	0.291	0.136
600	1.145	0.111	0.0515
550	1.215	0.0371	0.0173
500	1.293	0.0110	0.00514
450	1.383	0.00270	0.00127
425	1.432	0.00126	0.00059

^aCalculated from empirical equations.

PLATINUM-ZINC

A. Phase Information1. Phase Diagram

The phase diagram for the platinum-zinc system is reported in Hansen and Anderko⁵⁰ (p. 1147). A complex sequence of intermediate phases of wide composition range is shown.

2. Intermetallic Phases

The structures of platinum-zinc intermetallic phases given by Stanton *et al.*¹³⁹ (p. 15) in their review are:

Compound*	Crystal Class	Lattice Parameters, Å°	References
PtZn	Cubic	a = 18.116	37, 107
PtZn ₈			107
PtZn ₂ (ξ)	Hexagonal	a = 4.10 c = 2.74	107
PtZn (ν)	Tetragonal	a = 4.03 c = 3.47	105, 107
Pt ₃ Zn	Cubic	a = 3.89	107

*All phases have a range of composition.

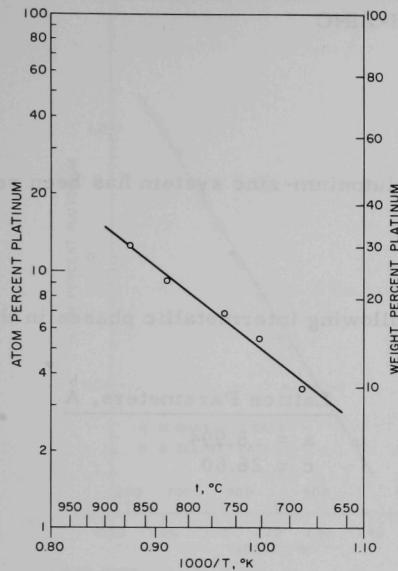
B. Solubility Data

Nowotny *et al.*¹⁰⁷ determined the solubility of platinum in liquid zinc by thermal analysis. Their measurements cover the range of 688-869°C and are shown in Fig. 28. The direct measurements may be represented by the following empirical equations over the range of 675-875°C:

$$\log (a/o \text{ Pt}) = 3.881 - 3176T^{-1};$$

$$\log (w/o \text{ Pt}) = 3.917 - 2780T^{-1}.$$

Experimental data are given in Table LX, and calculated values of the solubility at 25°C intervals are given in Table LXI.



108-7568

Fig. 28. Solubility of Platinum in Liquid Zinc

TABLE LX. Solubility of Platinum in Liquid Zinc: Experimental Data^a

$t, {}^{\circ}\text{C}$	$\frac{1000}{T, {}^{\circ}\text{K}}$	Platinum, w/o	Platinum, a/o
869	0.876	30.1	12.6
825	0.911	23.2	9.2
762	0.966	18.1	6.9
728	0.999	14.8	5.5
688	1.0404	9.8	3.5

^aH. Nowotny et al.,¹⁰⁷TABLE LXI. Solubility of Platinum in Liquid Zinc: Calculated^a

$t, {}^{\circ}\text{C}$	$\frac{1000}{T, {}^{\circ}\text{K}}$	Platinum, w/o	Platinum, a/o
875	0.871	31.3	13.03
850	0.890	27.6	11.30
825	0.911	24.3	9.75
800	0.932	21.2	8.35
775	0.953	18.4	7.09
750	0.977	15.83	5.98
725	1.002	13.54	5.00
700	1.028	11.48	4.14
675	1.055	9.65	3.40

^aCalculated from empirical equations.

PLUTONIUM-ZINC

A. Phase Information

1. Phase Diagram

The phase diagram for the plutonium-zinc system has been reported by Cramer, Ellinger, and Land.³¹

2. Intermetallic Phases

Cramer *et al.*³¹ report the following intermetallic phases in the plutonium-zinc system:

Compound	Crystal Class	Lattice Parameters, Å
Pu ₂ Zn ₁₇	Hexagonal	a = 8.994 c = 26.60
PuZn ₈		
Pu ₂ Zn ₉		
PuZn ₂	Face-centered Cubic	a = 7.760 (Pu rich) a = 7.741 (Zn rich)

B. Solubility Data

Elliott and Sweezer,³⁸ and Johnson and Chasanov⁶⁸ measured the solubility of plutonium in liquid zinc by analysis of filtered samples. Their data cover the range of 450-750°C and are presented in Fig. 29. The direct measurements may be represented by the following empirical equations over the range of 450-750°C:

$$\log (a/o \text{ Pu}) = 6.594 - 6637T^{-1};$$

$$\log (w/o \text{ Pu}) = 7.108 - 6588T^{-1}.$$

Experimental data are given in Table LXII, and calculated values of the solubility at 50°C intervals are given in Table LXIII.

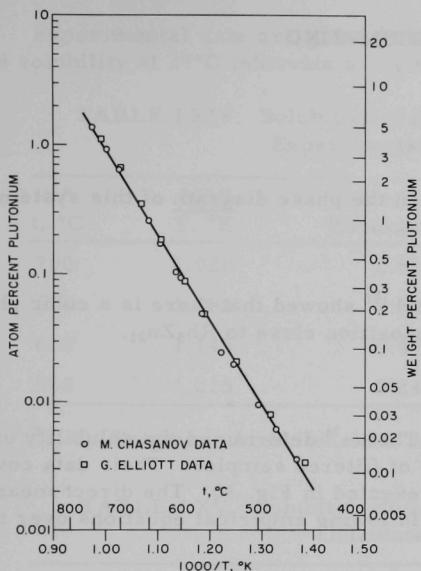


Fig. 29

Solubility of Plutonium in Liquid Zinc

108-7569

TABLE LXII. Solubility of Plutonium in Liquid Zinc: Experimental Data

t, °C	$\frac{1000}{T}$, °K	Plutonium, w/o	Plutonium, a/o
752.2 ^b	0.975	4.82	1.35
735 ^a	0.992	4.00	1.11
725.4 ^b	1.002	3.27	0.906
700.8 ^b	1.027	2.35	0.646
699 ^a	1.029	2.39	0.657
663 ^a	1.068	1.27	0.346
650.2 ^b	1.083	0.962	0.257
632.2 ^b	1.105	0.641	0.171
630 ^a	1.107	0.693	0.184
607.7 ^b	1.135	0.384	0.102
602.1 ^b	1.143	0.352	0.0935
596 ^a	1.151	0.327	0.0868
570.7 ^b	1.185	1.185	0.0492
568 ^a	1.189	0.182	0.0483
545.6 ^b	1.221	0.0911	0.0242
530.0 ^b	1.245	0.0737	0.0196
526 ^a	1.251	0.0780	0.0207
501 ^b	1.292	0.0356	0.00946
487 ^a	1.316	0.0300	0.00707
481.2 ^b	1.326	0.0340	0.00611
458.5 ^b	1.367	0.0134	0.00356
450 ^a	1.383	0.0127	0.00337

^aG. Elliott and R. Sweezer.³⁸^bI. Johnson and M. G. Chasanov.⁶⁸

TABLE LXIII. Solubility of Plutonium in Liquid Zinc: Calculated^a

t, °C	$\frac{1000}{T}$, °K	Plutonium, w/o	Plutonium, a/o
750	0.977	4.67	1.281
700	1.028	2.18	0.594
650	1.083	0.937	0.254
600	1.145	0.366	0.0984
550	1.215	0.127	0.0340
500	1.293	0.0387	0.0102
450	1.383	0.00996	0.00261

^aCalculated from empirical equations.

RHODIUM-ZINC

A. Phase Information1. Phase Diagram

No data are available on the phase diagram of this system.

2. Intermetallic Phases

Preliminary X-ray work¹⁵⁰ showed that there is a cubic phase (isotopic with γ brass) with a composition close to $\text{Rh}_5\text{Zn}_{21}$.

B. Solubility Data

Knighton, Chilenskas, and Thelen⁷⁴ determined the solubility of rhodium in liquid zinc by analysis of filtered samples. Their data covered the range of 550-700°C and are presented in Fig. 30. The direct measurements may be represented by the following empirical equations over the range of 550-700°C:

$$\log (\text{a/o Rh}) = 6.045 - 5762T^{-1};$$

$$\log (\text{w/o Rh}) = 6.222 - 5655T^{-1}.$$

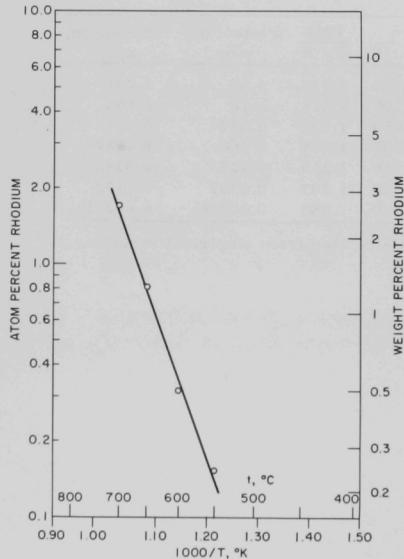


Fig. 30.
Solubility of Rhodium in Liquid Zinc

Experimental data are given in Table LXIV, and calculated values of the solubility at 25°C intervals are given in Table LXV.

TABLE LXIV. Solubility of Rhodium in Liquid Zinc:
Experimental Data^a

$t, ^\circ C$	$\frac{1000}{T, ^\circ K}$	Rhodium, w/o	Rhodium, a/o
700	1.028	2.66	1.70
650	1.083	1.27	0.811
600	1.145	0.495	0.315
550	1.215	0.241	0.153

^aJ. B. Knighton, A. Chilenskas, and V. N. Thelen.

TABLE LXV. Solubility of Rhodium in Liquid Zinc:
Calculated^a

$t, ^\circ C$	$\frac{1000}{T, ^\circ K}$	Rhodium, w/o	Rhodium, a/o
700	1.028	2.58	1.65
675	1.055	1.81	1.157
650	1.083	1.249	0.797
625	1.113	0.843	0.537
600	1.145	0.557	0.354
575	1.179	0.359	0.228
550	1.215	0.225	0.143

^aCalculated from empirical equations.

RUTHENIUM-ZINC

A. Phase Information1. Phase Diagram

No data are available on the phase diagram of the ruthenium-zinc system.

2. Intermetallic Phases

No data are available for the structure or composition of the intermetallic phases in the ruthenium-zinc system.

B. Solubility Data

Knighton, Burris, and Feder,⁷³ Johnson and Anderson,⁶⁵ and Martin⁹⁰ determined the solubility of ruthenium in zinc by analysis of filtered samples. Their data cover the range of 425-750°C and are presented in Fig. 31. The direct measurements^{65,73} may be presented by the following empirical equations over the range of 450-750°C:

$$\log (a/o \text{ Ru}) = 5.905 - 6191T^{-1};$$

$$\log (w/o \text{ Ru}) = 6.088 - 6187T^{-1}.$$

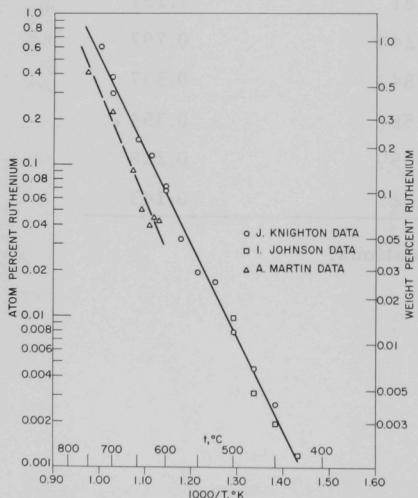


Fig. 31
Solubility of Ruthenium in Liquid Zinc

Experimental data are given in Table LXVI, and calculated values of the solubility at 50°C intervals are given in Table LXVII.

TABLE LXVI. Solubility of Ruthenium in Liquid Zinc:
Experimental Data

t, °C	$\frac{1000}{T, ^\circ K}$	Ruthenium, w/o	Ruthenium, a/o	t, °C	$\frac{1000}{T, ^\circ K}$	Ruthenium, w/o	Ruthenium, a/o
725 ^a	1.002	0.937	0.607	475 ^a	1.337	0.007	0.0045
700 ^a	1.028	0.586	0.380	475 ^b	1.337	0.0048	0.0031
700 ^a	1.028	0.46	0.296	450 ^a	1.383	0.0040	0.0026
650 ^a	1.083	0.226	0.146	450 ^b	1.383	0.0030	0.00194
650 ^a	1.083	0.221	0.143	425 ^b	1.432	0.00185	0.00120
625 ^a	1.113	0.176	0.114	754 ^c	1.974	0.630	0.407
600 ^a	1.145	0.111	0.071	700 ^c	1.028	0.344	0.222
600 ^a	1.145	0.104	0.067	660 ^c	1.072	0.139	0.090
575 ^a	1.179	0.050	0.032	643 ^c	1.092	0.077	0.050
550 ^a	1.215	0.030	0.0194	628 ^c	1.110	0.061	0.0394
525 ^a	1.253	0.026	0.0168	620 ^c	1.120	0.069	0.0446
500 ^b	1.293	0.015	0.0097	611 ^c	1.131	0.065	0.0420
500 ^a	1.293	0.012	0.0078				

^aJ. B. Knighton, L. Burris, Jr., and H. Feder.⁷³

^bI. Johnson and K. E. Anderson.⁶⁵

^cA. E. Martin.⁹⁰

TABLE LXVII. Solubility of Ruthenium in Liquid Zinc:
Calculated^a

t, °C	$\frac{1000}{T, ^\circ K}$	Ruthenium, w/o	Ruthenium, a/o
750	0.977	1.099	0.714
700	1.028	0.538	0.349
650	1.083	0.243	0.157
600	1.145	0.100	0.0650
550	1.215	0.0373	0.0241
500	1.293	0.0122	0.00788
450	1.383	0.00341	0.00220

^aCalculated from empirical equations.

ANTIMONY-ZINC

A. Phase Information1. Phase Diagram

The phase diagram for the antimony-zinc system is reported in Hansen and Anderko⁵⁰ (pp. 1183 and 1184).

2. Intermetallic Phases

The structures of antimony-zinc intermetallic phases given by Stanton et al.¹³⁹ (p. 11) in their review are:

Compound	Crystal Class	Lattice Parameters, Å	References
Sb ₂ Zn ₃ (ϵ , ζ , η)*			47, 140
Sb ₃ Zn ₄ (β , γ)*			18, 140
SbZn	Orthorhombic	a = 6.218 b = 7.741 c = 8.115	2, 47, 140

*These phases have a small composition range, and each phase has several modifications.

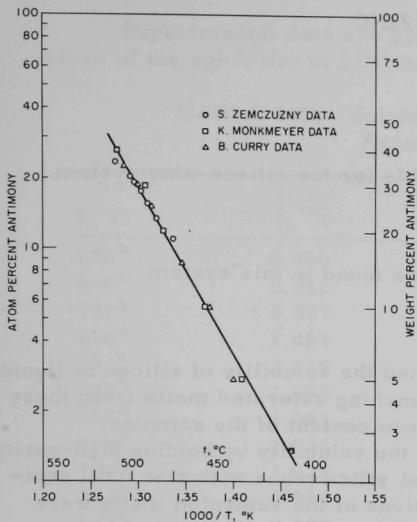
B. Solubility Data

Zemczuzny,¹⁵¹ Monkmeyer,⁹⁹ and Curry³² determined the solubility of antimony (Sb₂Zn₃) in liquid zinc by thermal analysis. Their measurements covered the range of 411-511°C and are presented in Fig. 32. The direct measurements may be represented by the following empirical equations over the range of 420-510°C:

$$\log (a/o \text{ Sb}) = 10.540 - 7139T^{-1};$$

$$\log (w/o \text{ Sb}) = 10.179 - 6703T^{-1}.$$

Experimental data are given in Table LXVIII, and calculated values of the solubility at 10°C intervals are given in Table LXIX.



108-7540

Fig. 32. Solubility of Antimony
in Liquid Zinc

TABLE LXVIII. Solubility of
Antimony in Liquid Zinc:
Experimental Data

t, °C	$\frac{1000}{T, ^\circ\text{K}}$	Antimony, w/o	Antimony, a/o
510.5 ^a	1.276	36.4	23.5
510 ^b	1.277	40.0	26.4
505 ^c	1.285	35.0	22.4
501 ^a	1.292	32.2	20.2
498.5 ^a	1.296	30.6	19.1
496 ^c	1.300	30.0	18.7
494 ^a	1.303	28.1	17.6
492 ^b	1.307	29.8	18.6
490 ^a	1.310	25.4	15.5
488 ^c	1.314	25.0	15.1
485 ^a	1.319	22.5	13.5
481 ^b	1.326	20.0	11.9
474.5 ^a	1.337	18.6	11.0
470 ^c	1.346	15.0	8.66
457 ^c	1.370	10.0	5.63
454 ^b	1.375	10.0	5.63
441 ^b	1.400	5.0	2.75
437 ^c	1.408	5.0	2.75
411 ^b	1.462	2.5	1.36
411 ^c	1.462	2.5	1.36

^aS. F. Zenczczny¹⁵^bK. Monkmyer⁹⁹^cB. E. Curry.³²

TABLE LXIX. Solubility of Antimony in Liquid Zinc:
Calculated^a

t, °C	$\frac{1000}{T, ^\circ\text{K}}$	Antimony, w/o	Antimony, a/o
510	1.277	41.7	26.5
500	1.293	32.3	20.2
490	1.310	24.9	15.31
480	1.328	19.0	11.50
470	1.346	14.4	8.57
460	1.364	10.88	6.34
450	1.383	8.14	4.65
440	1.402	6.03	3.38
430	1.422	4.43	2.44
420	1.443	3.23	1.74

^aCalculated from empirical equations.

SILICON-ZINC

A. Phase Information1. Phase Diagram

No phase diagram is available for the silicon-zinc system.

2. Intermetallic Phases

No intermetallic phases were found in this system.

B. Solubility Data

Moissan and Siemens⁹⁸ determined the solubility of silicon in liquid zinc over the range of 600-850°C by quenching saturated melts from these temperatures and analyzing for the silicon content of the samples.

Thurmond and Kowalchik¹⁴² determined the solubility by holding high-purity, single-crystal ingots of silicon in sealed silica tubes with zinc until equilibrium was established. The compositions of the saturated melts were obtained from the loss in weight of the silicon ingot. These data are presented in Fig. 33. The most recent measurements may be represented by the following empirical equations over the range of 650-850°C:

$$\log (a/o \text{ Si}) = 3.977 - 3701T^{-1};$$

$$\log (w/o \text{ Si}) = 3.666 - 3750T^{-1}.$$

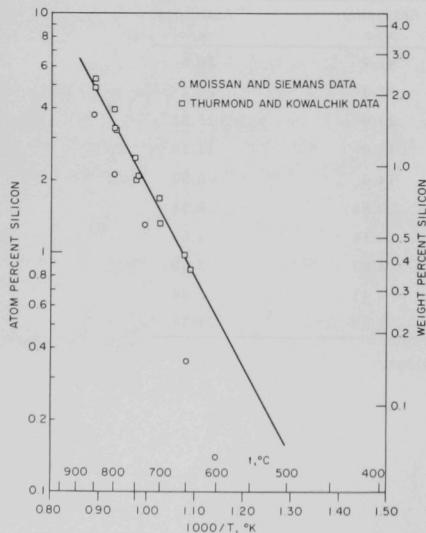


Fig. 33
Solubility of Silicon in Liquid Zinc

Experimental data are presented in Table LXX, and calculated values of the solubility at 25°C intervals are given in Table LXXI.

TABLE LXX. Solubility of Silicon in Liquid Zinc:
Experimental Data

t, °C	$\frac{1000}{T, ^\circ K}$	Silicon, w/o	Silicon, a/o
850 ^a	0.890	1.62	3.7
800 ^a	0.932	0.92	2.1
730 ^a	0.997	0.57	1.3
650 ^a	1.083	0.15	0.35
600 ^a	1.145	0.06	0.14
642 ^b	1.093	0.368	0.845
652 ^b	1.081	0.420	0.962
698 ^b	1.030	0.672	1.31
700 ^b	1.028	0.734	1.68
744 ^b	0.983	0.908	2.08
747 ^b	0.980	0.873	2.00
751 ^b	0.976	1.08	2.47
796 ^b	0.935	1.39	3.21
798 ^b	0.934	1.42	3.25
799 ^b	0.933	1.72	3.94
844 ^b	0.895	2.12	4.86
846 ^b	0.893	2.30	5.26

^aH. Moissan and F. Siemens.⁹⁸

^bC. D. Thurmond and M. Kowalchik.¹⁴²

TABLE LXXI. Solubility of Silicon in Liquid Zinc:
Calculated^a

t, °C	$\frac{1000}{T, ^\circ K}$	Silicon, w/o	Silicon, a/o
850	0.890	2.13	4.82
825	0.911	1.78	4.03
800	0.932	1.48	3.37
775	0.954	1.23	2.79
750	0.977	1.00	2.30
725	1.002	0.810	1.86
700	1.028	0.647	1.49
675	1.055	0.512	1.18
650	1.083	0.402	0.931

^aCalculated from empirical equations.

TIN-ZINC

A. Phase Information1. Phase Diagram

The phase diagram of the tin-zinc system is reported by Hansen and Anderko⁵⁰ (p. 1218). This is a simple eutectic system with the eutectic occurring at 15.2 a/o zinc and 199°C.

2. Intermetallic Phases

No intermetallic phases were found in the system.

B. Solubility Data

Lorenz and Plumbridge⁸⁶ and Heycock and Neville⁶⁰ determined the liquidus by thermal analysis. Their measurements cover the range of 198-420°C. The experimental data are given in Table LXXII, and interpolated values of the solubility in Table LXXIII.

TABLE LXXII. Liquid-phase Composition of Tin-Zinc System: Experimental Data

t, °C	1000 T, °K	Tin, w/o	Tin, a/o
232 ^a	1.980	100.0	100.0
228 ^a	1.995	99.45	99.00
224 ^a	2.012	98.89	98.00
221 ^a	2.024	98.33	87.00
215 ^a	2.049	96.17	93.25
210 ^a	2.070	95.50	92.18
206 ^a	2.087	93.91	89.46
197.8 ^b	2.123	89.29	82.10
221 ^a	2.024	89.00	81.49
223 ^a	2.016	88.50	80.87
228.6 ^b	1.993	88.35	80.77
234.8 ^b	1.969	87.42	79.39
235 ^a	1.968	87.00	78.64
243 ^a	1.937	84.50	74.96
281.0 ^b	1.805	80.32	69.36
297.9 ^b	1.751	76.59	64.48
323.7 ^b	1.675	69.23	55.52
329 ^a	1.661	61.90	47.19
342.7 ^b	1.624	61.33	46.80
355.6 ^b	1.590	49.07	34.83
370 ^a	1.555	35.04	20.00
378 ^a	1.536	24.48	15.83
380.5 ^b	1.530	23.08	14.26
393.1 ^b	1.501	11.77	6.88
394 ^a	1.499	12.00	7.00
409.8 ^b	1.464	3.23	1.81
418.8 ^b	1.445	0.0	0.0

TABLE LXXIII. Liquid-phase Composition of Tin-Zinc System: Calculated^a

t, °C	Zinc-rich Phase		Zinc-rich Phase	
	Tin, w/o	Tin, a/o	Tin, w/o	Tin, a/o
198	90.6	84.2	90.6	84.2
200	92.0	86.4	90.5	84.1
210	95.4	92.0	89.8	83.0
220	97.8	96.1	89.0	81.7
230	99.7	99.5	88.1	80.2
232	100.0	100.0	87.5	79.5
250	-	-	85.6	76.5
275	-	-	81.5	70.8
300	-	-	75.5	63.0
325	-	-	68.2	54.7
350	-	-	57.3	42.5
375	-	-	25.7	16.0
400	-	-	7.9	4.5
419	-	-	0.0	0.0

^a Read from a graph of the data.

^a R. Lorenz and D. Plumbridge.⁸⁶

^b C. T. Heycock and F. H. Neville.⁶⁰

STRONTIUM-ZINC

A. Phase Information

1. Phase Diagram

No phase diagram is available for the strontium-zinc system.

2. Intermetallic Phases

The structures of strontium-zinc intermetallic phases given by Stanton et al.¹³⁹ (p. 8) in their review are:

Compound	Crystal Class	Lattice Parameters, Å	References
SrZn ₁₃	Cubic	a = 12.215	69
SrZn ₅	Orthorhombic	a = 5.32 b = 6.72 c = 13.15	10

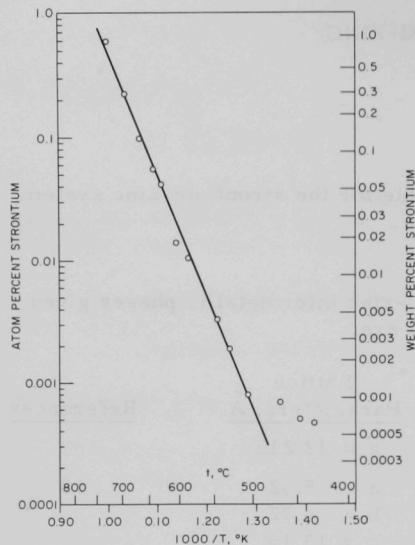
B. Solubility Data

Johnson, Anderson, and Bartos⁶⁷ determined the solubility of strontium in liquid zinc by analysis of filtered samples. Their measurements cover the range of 428-727°C, and their data are presented in Fig. 34. The direct measurements may be represented by the following empirical equations over the range of 450-725°C:

$$\log (a/o Sr) = 9.615 - 9936T^{-1};$$

$$\log (w/o Sr) = 9.733 - 9930T^{-1}.$$

The experimental data are given in Table LXXIV, and calculated values of the solubility at 25°C intervals are given in Table LXXV.



108-7567

Fig. 34. Solubility of Strontium in Liquid Zinc

TABLE LXXIV. Solubility of Strontium in Liquid Zinc:
Experimental Data^a

$t, ^\circ C$	$1000/T, ^\circ K$	Strontium, w/o	Strontium, a/o
727	1.000	0.78	0.58
692	1.036	0.30	0.22
666	1.065	0.13	0.097
642	1.093	0.073	0.055
628	1.110	0.055	0.041
604	1.140	0.018	0.014
587	1.163	0.014	0.010
545	1.222	0.0043	0.0032
529	1.247	0.0025	0.0019
506	1.283	0.0011	0.00079
468	1.349	0.00091	0.00068
447	1.389	0.00067	0.00050
433	1.416	0.00062	0.00046
428	1.426	0.00012	0.000094

^aI. Johnson, K. E. Anderson, and J. Bartos.⁶⁷

TABLE LXXV. Solubility of Strontium in Liquid Zinc:
Calculated^a

$t, ^\circ C$	$1000/T, ^\circ K$	Strontium, w/o	Strontium, a/o
725	1.002	0.610	0.457
700	1.028	0.339	0.254
675	1.055	0.182	0.1366
650	1.083	0.0948	0.0711
625	1.113	0.0476	0.0356
600	1.145	0.0230	0.01719
575	1.179	0.01061	0.00794
550	1.215	0.00468	0.00350
525	1.253	0.00196	0.001465
500	1.293	0.000776	0.000580
475	1.337	0.000289	0.000216
450	1.383	0.0001005	0.000075

^aCalculated from empirical equations.

TECHNETIUM-ZINC

A. Phase Information

1. Phase Diagram

The phase diagram for the technetium-zinc system has been published by Casanov, Johnson, and Schablaske.²¹ Two intermediate phases are reported, a zinc-rich phase with a zinc-to-technetium atom ratio of from 15 to 18, and a phase with the formula TcZn₆. The zinc-rich phase undergoes peritectic reaction to TcZn₆, and a liquid phase at 544°C, while TcZn₆ peritectic alloy decomposes into technetium metal and a zinc-rich liquid phase at 950°C. The nature of the phase diagram above 950°C is unknown.

2. Intermediate Phases

The X-ray diffraction pattern for TcZn₆ can be indexed on the basis of a face-centered cubic cell with $a_0 = 7.588 \text{ \AA}$. The TcZn₆ structure is related to the AuCu₃-type structure. The structure of the zinc-rich intermediate phase was not determined.

B. Solubility Data

Chasanov, Johnson, and Schablaske²¹ determined the solubility of technetium in liquid zinc by the analysis of filtered samples. The data shown in Fig. 35 may be represented by the equations:

$$470-544^\circ\text{C}: \log (\text{a/o Tc}) = 6.431 - 7159T^{-1};$$

$$544-758^\circ\text{C}: \log (\text{a/o Tc}) = 9.413 - 15690T^{-1} + 4.979 \times 10^6T^{-2}.$$

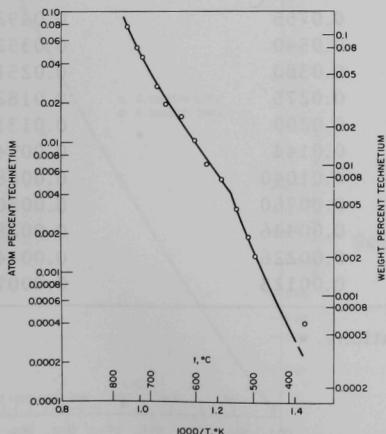


Fig. 35

Solubility of Technetium
in Liquid Zinc

The experimental data are given in Table LXXVI, and calculated values of the solubility are given in Table LXXVII.

TABLE LXXVI. Solubility of Technetium
in Liquid Zinc: Experimental Data^a

t, °C	$\frac{1000}{T, ^\circ K}$	Technetium, w/o	Technetium, a/o
757.5	0.970	0.118	0.0779
733.7	0.993	0.0838	0.0553
718.3	1.009	0.0673	0.0444
683.6	1.045	0.0407	0.0269
662.2	1.069	0.0296	0.0195
629.6	1.108	0.0236	0.0156
600.9	1.144	0.0156	0.0103
580.4	1.172	0.0102	0.00674
552.3	1.212	0.00779	0.00514
527.0	1.250	0.00456	0.00301
506.7	1.282	0.00280	0.00185
496.7	1.299	0.00206	0.00132
428.4	1.425	0.0006	0.0004

^aM. G. Chasanov, I. Johnson, and R. V. Schablaske.²¹

TABLE LXXVII. Solubility of Technetium
in Liquid Zinc: Calculated^a

t, °C	$\frac{1000}{T, ^\circ K}$	Technetium, w/o	Technetium, a/o
750	0.977	0.1040	0.0682
725	1.002	0.0755	0.0492
700	1.028	0.0540	0.0352
675	1.055	0.0380	0.0251
650	1.083	0.0275	0.0182
625	1.113	0.0200	0.01315
600	1.145	0.0144	0.00944
575	1.79	0.01040	0.00684
550	1.215	0.00760	0.00500
525	1.253	0.00446	0.00289
500	1.293	0.00226	0.00149
475	1.337	0.00123	0.000723

^aCalculated from empirical equations.*

THORIUM-ZINC

A. Phase Information

1. Phase Diagram

The phase diagram of the thorium-zinc system has been reported by Chiotti and Gill.²⁵

2. Intermetallic Phases

The phases in the thorium-zinc system reported by Chiotti and Gill are:

Compound	Crystal Class	Lattice Parameters, Å	References
Th ₂ Zn ₁₇	Rhombohedral	a = 9.03 c = 13.20	87
ThZn ₄	Body-centered Tetragonal	a = 4.273 c = 10.359	25, 87
ThZn ₂	Hexagonal	a = 9.03 c = 7.39	25, 87
Th ₂ Zn	Body-centered Tetragonal	a = 7.60 c = 5.64	9

B. Solubility Data

The solubility of thorium in liquid zinc has been determined by Chiotti and Gill²⁵ by thermal analysis and by Martin, Knighton, and Feder⁹⁴ by analysis of filtered samples. Their measurements covered the range of 450-1015°C, and the data are presented in Fig. 36. The direct measurements may be represented by the following empirical equations over the

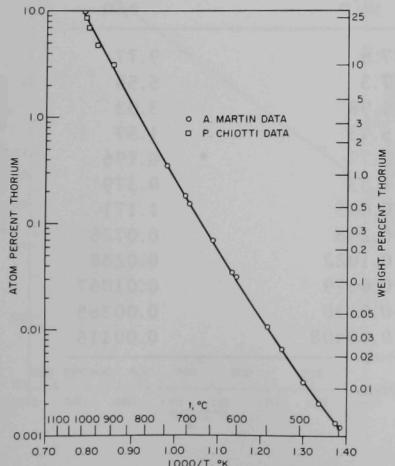


Fig. 36
Solubility of Thorium in Liquid Zinc

range of 450-1000°C:

$$\log (a/o \text{ Th}) = 8.231 - 10719T^{-1} + 1.910 \times 10^6 T^{-2};$$

$$\log (w/o \text{ Th}) = 6.706 - 6.707T^{-1}.$$

The experimental data are presented in Table LXXVIII, and calculated values of the solubility at 50°C intervals are given in Table LXXIX.

TABLE LXXVIII. Solubility of Thorium in Liquid Zinc: Experimental Data

t, °C	$\frac{1000}{T, ^\circ K}$	Thorium, w/o	Thorium, a/o	t, °C	$\frac{1000}{T, ^\circ K}$	Thorium, w/o	Thorium, a/o
1015 ^a	0.777	29.5	10.5	644.7 ^b	1.089	0.247	0.0696
1010 ^a	0.780	29.2	10.4	609.8 ^b	1.133	0.123	0.0346
995 ^a	0.789	28.1	9.9	601.1 ^b	1.144	0.111	0.0313
990 ^a	0.792	25.0	8.6	548.4 ^b	1.217	0.0373	0.0105
980 ^a	0.798	20.4	6.9	526.6 ^b	1.250	0.0231	0.00650
950 ^a	0.818	15.0	4.74	496.2 ^b	1.300	0.0113	0.00318
895 ^a	0.856	10.2	3.10	475.5 ^b	1.336	0.00708	0.00200
746.2 ^b	0.981	1.23	0.347	455.0 ^b	1.373	0.00465	0.00131
703.8 ^b	1.024	0.639	0.181	498.9 ^b	1.385	0.00426	0.00120
694.9 ^b	1.033	0.541	0.152				

^aP. Chiotti and K. Gill.²⁵

^bA. E. Martin, J. B. Knighton, and H. M. Feder.⁹⁴

TABLE LXXIX. Solubility of Thorium
in Liquid Zinc: Calculated^a

t, °C	$\frac{1000}{T, ^\circ K}$	Thorium, w/o	Thorium, a/o
1000	0.785	27.8	9.77
950	0.818	17.3	5.55
900	0.852	9.98	3.03
850	0.890	5.43	1.59
800	0.932	2.77	0.796
750	0.977	1.33	0.379
700	1.028	0.605	1.171
650	1.083	0.258	0.0726
600	1.145	0.1022	0.0288
550	1.215	0.0379	0.01067
500	1.293	0.0130	0.00365
450	1.383	0.00408	0.00115

^aCalculated from empirical equations.

TITANIUM-ZINC

A. Phase Information

1. Phase Diagram

The phase diagram for the titanium-zinc system is reported by Hansen and Anderko⁵⁰ (p. 1244) in the zinc-rich region.

2. Intermetallic Phases

The structures of titanium-zinc intermetallic phases given by Stanton *et al.*¹³⁹ (pp. 9-10) in their review are:

Compound	Crystal Class	Lattice Parameters, Å	References
TiZn			4, 41, 83
TiZn ₃	Cubic	a = 3.9322	119
TiZn ₂	Hexagonal	a = 5.064 c = 8.210	119

B. Solubility Data

Gebhardt⁴¹ determined the solubility of titanium in zinc by thermal analysis. His measurements covered the temperature range of 460-1000°C and are presented in Fig. 37. The data may be represented by the

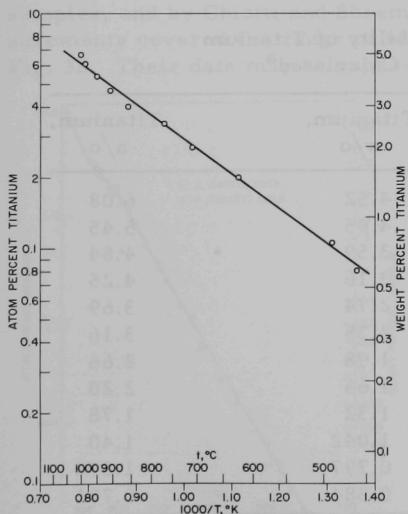


Fig. 37
Solubility of Titanium in Liquid Zinc

following empirical equations over the temperature of 450-1000°C:

$$\log (a/o \text{ Ti}) = 1.948 - 1482T^{-1};$$

$$\log (w/o \text{ Ti}) = 1.819 - 1483T^{-1}.$$

The experimental data are given in Table LXXX, and calculated values of the solubility at 50°C intervals in Table LXXXI.

TABLE LXXX. Solubility of Titanium
in Liquid Zinc: Experimental Data^a

t, °C	<u>1000</u> T, °K	Titanium, w/o	Titanium, a/o
1000	0.785	5.0	6.7
990	0.792	4.5	6.1
950	0.818	4.0	5.4
910	0.845	3.5	4.7
860	0.883	3.0	4.0
770	0.959	2.5	3.4
710	1.017	2.0	2.7
625	1.113	1.5	2.0
490	1.340	0.82	1.1
460	1.364	0.59	0.80

^aE. Gebhardt.⁴¹

TABLE LXXXI. Solubility of Titanium
in Liquid Zinc: Calculated^a

t, °C	<u>1000</u> T, °K	Titanium, w/o	Titanium, a/o
1000	0.785	4.52	6.08
950	0.818	4.05	5.45
900	0.852	3.59	4.84
850	0.890	3.16	4.25
800	0.932	2.74	3.69
750	0.977	2.35	3.16
700	1.028	1.98	2.66
650	1.083	1.63	2.20
600	1.145	1.32	1.78
550	1.215	1.042	1.40
500	1.293	0.797	1.074
450	1.383	0.584	0.791

^aCalculated from empirical equations.

URANIUM-ZINC

A. Phase Information1. Phase Diagram

The phase diagram for the uranium-zinc system is reported in Hansen and Anderko⁵⁰ (p. 1250).

2. Intermetallic Phases

The structure of the uranium-zinc intermetallic phase reported by Stanton *et al.*¹³⁹ (p. 11) in their review is:

Compound	Crystal Class	Lattice Parameters, Å	References
U_2Zn_{17}	Hexagonal	$a = 8.99$ $c = 26.35$	22, 87, 146

Martin⁹² reports the solid phase in equilibrium with the saturated solution to be U_2Zn_{23} below about 830°C and U_2Zn_{17} above 830°C. It seems certain that there is more than one intermetallic phase in this system.

B. Solubility Data

The solubility of uranium in liquid zinc has been determined by Martin and Wach,^{92,93} and Martin, Uhle, and Wach⁹¹ by analysis of filtered samples, and by Chiotti and Shoemaker²³ by thermal analysis. Their measurements covered the range of 425-957°C, and the data are presented in Fig. 38. Their data may be represented by the following two sets of

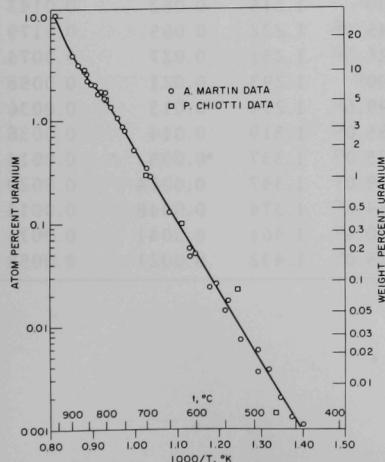


Fig. 38
Solubility of Uranium in Liquid Zinc

empirical equations over the ranges of 419-800°C and 800-957°C:

800°C < t < 957°C

$$\log (a/o \text{ U}) = 21.771 - 42250T^{-1} + 2.051 \times 10^7 T^{-2};$$

$$\log (w/o \text{ U}) = 21.860 - 41780T^{-1} + 2.052 \times 10^7 T^{-2}.$$

419°C < t < 800°C

$$\log (a/o \text{ U}) = 6.579 - 6857T^{-1};$$

$$\log (w/o \text{ U}) = 7.101 - 6837T^{-1}.$$

The experimental data are given in Table LXXXII, and calculated values of the solubility at 50°C intervals in Table LXXXIII.

TABLE LXXXII. Solubility of Uranium in Liquid Zinc: Experimental Data

t, °C	$\frac{1000}{T, ^\circ\text{K}}$	Uranium, w/o	Uranium, a/o	t, °C	$\frac{1000}{T, ^\circ\text{K}}$	Uranium, w/o	Uranium, a/o
957 ^a	0.813	30.0	10.5	700 ^d	1.028	1.96	0.29
901.4 ^b	0.851	13.7	4.18	691 ^c	1.037	1.04	0.288
900.4 ^b	0.852	14.1	4.20	650 ^c	1.083	0.467	0.129
881.0 ^b	0.866	11.6	3.39	625 ^d	1.113	0.38	0.102
862 ^a	0.881	10.70	3.11	611 ^c	1.131	0.210	0.058
862 ^a	0.881	10.53	3.05	610.5 ^c	1.132	0.176	0.0484
856 ^a	0.886	9.75	2.80	600 ^c	1.145	0.186	0.0512
855.3 ^b	0.888	8.5	2.42	575.2 ^c	1.179	0.088	0.0242
841.9 ^b	0.897	7.9	2.24	563.9 ^c	1.195	0.096	0.0264
829 ^a	0.907	7.72	2.19	550 ^d	1.215	0.083	0.023
821.6 ^b	0.913	6.4	1.80	550 ^c	1.215	0.052	0.0143
814 ^a	0.920	6.71	1.89	545.1 ^c	1.222	0.065	0.0179
805 ^a	0.928	5.88	1.64	526.3 ^c	1.251	0.027	0.0074
800 ^c	0.932	6.47	1.86	500 ^c	1.293	0.021	0.0058
800 ^d	0.932	5.47	1.58	499.6 ^c	1.294	0.013	0.0036
786 ^a	0.944	4.87	1.39	485.0 ^c	1.319	0.014	0.0038
786 ^a	0.960	3.82	1.05	475.0 ^d	1.337	0.005	0.0014
756.2 ^c	0.971	3.10	0.871	469.0 ^c	1.347	0.0074	0.0020
750 ^c	0.977	2.81	0.788	454.6 ^c	1.374	0.0048	0.0013
729 ^c	0.998	1.86	0.518	440.4 ^c	1.401	0.0041	0.0011
700 ^c	1.028	1.25	0.346	425.0 ^c	1.432	0.0021	0.0058

^aA. E. Martin and C. Wach.⁹³

^bA. E. Martin and C. Wach.⁹²

^cA. E. Martin, R. Uhle, and C. Wach.⁹¹

^dP. Chiotti and H. Shoemaker.²³

TABLE LXXXIII. Solubility of Uranium
in Liquid Zinc: Calculated^a

t, °C	$\frac{1000}{T, ^\circ K}$	Uranium, w/o	Uranium, a/o
950	0.818	26.2	8.67
900	0.852	15.8	4.55
850	0.890	8.47	2.59
800	0.932	5.47	1.58
750	0.977	2.62	0.753
700	1.028	1.19	0.342
650	1.083	0.495	0.142
600	1.145	0.187	0.0533
550	1.215	0.0624	0.0178
500	1.293	0.0181	0.00537
450	1.383	0.00443	0.00125

^aCalculated from empirical equations.

VANADIUM-ZINC

A. Phase Information

1. Phase Diagram

The phase diagram of the vanadium-zinc system has been reported by Chasanov *et al.*²⁰

2. Intermetallic Phases

Two phases are reported by Chasanov *et al.*:²⁰

Compound	Crystal Class	Lattice Parameters, Å
VZn_3	Cubic	$a = 3.848$
V_4Zn_5	Body-centered	$a = 8.910$
	Tetragonal	$c = 3.227$

B. Solubility Data

Chasanov *et al.*²⁰ determined the solubility of vanadium in liquid zinc by analysis of filtered samples. Their measurements covered the range of 450-755°C, and the data are presented in Fig. 39. The direct

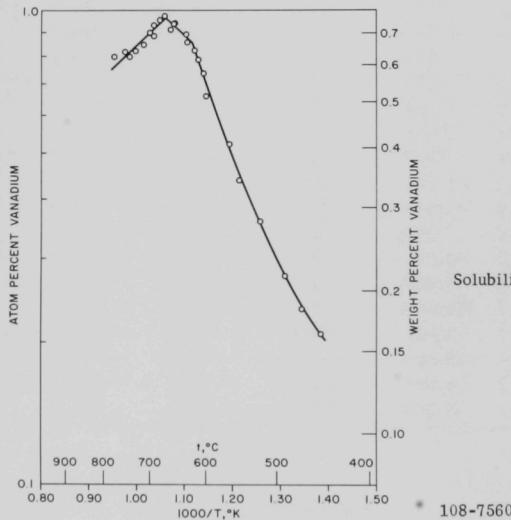


Fig. 39
Solubility of Vanadium in Liquid Zinc

108-7560

measurements may be represented by the following three sets of empirical equations over the ranges of 450-623°C, 623-670°C, and 670-756°C:

450-623°C

$$\log (a/o V) = 7.260 - 10010T^{-1} + 3.086 \times 10^6 T^{-2};$$

$$\log (w/o V) = 7.154 - 10030T^{-1} + 3.102 \times 10^6 T^{-2}.$$

623-670°C

$$\log (a/o V) = 0.9652 - 925.6T^{-1};$$

$$\log (w/o V) = 0.8570 - 924.8T^{-1}.$$

670-756°C

$$\log (a/o V) = -1.045 + 969.7T^{-1};$$

$$\log (w/o V) = -1.153 + 969.7T^{-1}.$$

The experimental data are given in Table LXXXIV, and calculated values of the solubility at 25°C intervals are given in Table LXXXV.

TABLE LXXXIV. Solubility of Vanadium in Liquid Zinc: Experimental Data^a

t, °C	1000 T, °K	Vanadium, w/o	Vanadium, a/o	t, °C	1000 T, °K	Vanadium, w/o	Vanadium, a/o
755.5	0.954	0.624	0.799	632.5	1.104	0.695	0.890
750.5	0.977	0.640	0.820	631.4	1.106	0.670	0.858
741.2	0.986	0.624	0.799	618.5	1.122	0.644	0.8525
729.4	0.998	0.641	0.821	612.5	1.129	0.614	0.787
712.5	1.015	0.661	0.847	604.5	1.139	0.575	0.737
699.5	1.028	0.702	0.899	600.5	1.145	0.514	0.659
693.5	1.035	0.728	0.932	564.5	1.194	0.407	0.522
692.4	1.036	0.690	0.884	550.4	1.214	0.342	0.438
680.5	1.049	0.746	0.956	521.5	1.258	0.280	0.359
671.5	1.059	0.760	0.973	490.4	1.310	0.215	0.276
660.4	1.071	0.712	0.912	470.5	1.345	0.183	0.235
654.4	1.079	0.732	0.938	449.5	1.384	0.162	0.208
651.5	1.082	0.733	0.939				

^aM. G. Chasanov *et al.*²⁰

TABLE LXXXV. Solubility of Vanadium
in Liquid Zinc: Calculated^a

t, °C	1000 T, °K	Vanadium, w/o	Vanadium, a/o
750	0.977	0.625	0.800
725	1.002	0.660	0.845
700	1.028	0.700	0.895
675	1.055	0.745	0.951
650	1.083	0.720	0.918
625	1.113	0.672	0.861
600	1.145	0.545	0.698
575	1.179	0.437	0.560
550	1.215	0.351	0.450
525	1.253	0.285	0.366
500	1.293	0.233	0.299
475	1.337	0.193	0.247
450	1.383	0.162	0.208

^aCalculated from empirical equations.

YTTRIUM-ZINC

A. Phase Information1. Phase Diagram

The phase diagram for the yttrium-zinc system has been reported by Chiotti, Mason, and Gill.²⁶

2. Intermetallic Phases

The phases in the yttrium-zinc system have been reported by Chiotti, Mason, and Gill.²⁶ Veleckis, Johnson, and Feder¹⁴⁵ used the record-ing effusion balance to study this system. The results of the two studies are in good agreement except for the phases YZn_{12} (which Chiotti reports as YZn_{11}) and $\text{YZn}_{4.5}$ (which Chiotti reports as YZn_4). The formulas assigned by Veleckis are given below:

Compound	Crystal Class	Lattice Parameters, Å	References
YZn_{12}	Body-centered Tetragonal	$a = 8.879$ $c = 5.201$	145
Y_2Zn_{17}	Hexagonal		
YZn_5	Hexagonal		
$\text{YZn}_{4.5}$			
YZn_4		$a = 4.402$ $b = 8.906$ $c = 12.934$	52
Y_3Zn_{11}			
YZn_3		$a = 6.690$ $b = 4.405$ $c = 10.111$	52
YZn_2	Orthorhombic	$a = 4.054$ $b = 7.143$ $c = 7.665$	52, 124
YZn	Cubic		

B. Solubility Data

Knighton⁷¹ determined the solubility of yttrium in liquid zinc by analysis of filtered samples. His data cover the range of 452-713°C and are presented in Fig. 40. The direct measurements may be represented by the following empirical equations over the range of 425-700°C:

$$\log (\text{a/o Y}) = 6.306 - 6139T^{-1};$$

$$\log (\text{w/o Y}) = 6.434 - 6135T^{-1}.$$

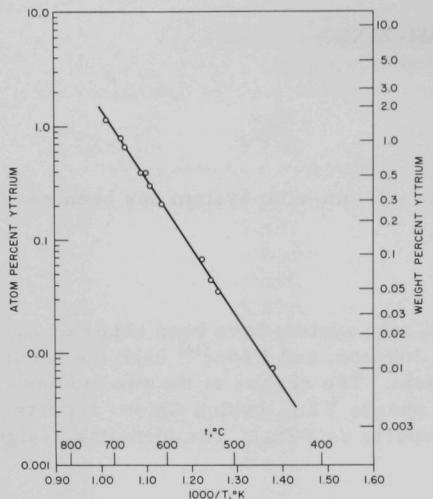


Fig. 40
Solubility of Yttrium in Liquid Zinc

The experimental data are given in Table LXXXVI, and calculated values of the solubility at 25°C intervals are given in Table LXXXVII.

TABLE LXXXVI. Solubility of Yttrium in Liquid Zinc:
Experimental Data^a

$t, {}^{\circ}\text{C}$	$1000/T, {}^{\circ}\text{K}$	Yttrium, w/o	Yttrium, a/o
713	1.014	1.54	1.14
682	1.047	1.17	0.79
676	1.054	0.90	0.66
644	1.090	0.53	0.39
635	1.101	0.53	0.39
628	1.110	0.41	0.30
607	1.136	0.28	0.206
544	1.224	0.091	0.067
532	1.242	0.060	0.044
521	1.259	0.047	0.0345
452	1.379	0.010	0.0073

^aJ. B. Knighton.⁷¹

TABLE LXXXVII. Solubility of Yttrium in Liquid Zinc:
Calculated^a

$t, {}^{\circ}\text{C}$	$1000/T, {}^{\circ}\text{K}$	Yttrium, w/o	Yttrium, a/o
700	1.028	1.348	0.994
675	1.055	0.919	0.678
650	1.083	0.614	0.452
625	1.113	0.401	0.295
600	1.145	0.256	0.188
575	1.179	0.159	0.1169
550	1.215	0.0957	0.0704
525	1.253	0.0559	0.0411
500	1.293	0.0315	0.0232
475	1.337	0.0171	0.0126
450	1.383	0.00891	0.00655
425	1.432	0.00443	0.00326

^aCalculated from empirical equations.

ZIRCONIUM-ZINC

A. Phase Information

1. Phase Diagram

The phase diagram for the zirconium-zinc system has been reported by Chiotti and Kilp.²⁸

2. Intermetallic Phases

The intermetallic phases in the zirconium-zinc system reported by Chiotti and Kilp²⁸ are:

Compound	Crystal Class	Lattice Parameters, Å
ZrZn ₁₄	Face-centered Cubic	a = 14.11
ZrZn ₆	Pseudo Body-centered Tetragonal	a = 12.7 c = 8.68
ZrZn ₃	Cubic	a = 16.3
ZrZn ₂	Face-centered Cubic	a = 7.396
ZrZn	Cubic	a = 3.336

B. Solubility Data

Knighton, Burris, and Feder⁷³ and Martin *et al.*⁹⁴ determined the solubility of zirconium in liquid zinc by analysis of filtered samples; Gebhardt⁴¹ and Chiotti and Kilp²⁸ determined solubility by thermal analysis. Their measurements covered the range of 420-745°C, and the data are presented in Fig. 41. The direct measurements may be represented by the following two sets of empirical equations over the ranges of 425-548°C and 548-750°C:

425-548°C

$$\log (a/o \text{ Zr}) = 8.878 - 7430T^{-1};$$

$$\log (w/o \text{ Zr}) = 9.013 - 7422T^{-1}.$$

548-750°C

$$\log (a/o \text{ Zr}) = 4.264 - 3606T^{-1};$$

$$\log (w/o \text{ Zr}) = 4.373 - 3577T^{-1}.$$

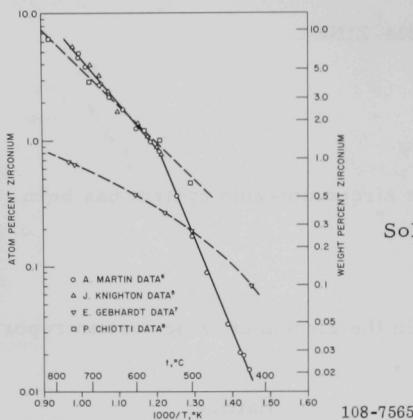


Fig. 41

Solubility of Zirconium in Liquid Zinc

The experimental data are given in Table LXXXVIII, and calculated values of the solubility at 25°C intervals in Table LXXXIX.

TABLE LXXXVIII. Solubility of Zirconium in Liquid Zinc: Experimental Data

t, °C	1000 T, °K	Zirconium, w/o	Zirconium, a/o	t, °C	1000 T, °K	Zirconium, w/o	Zirconium, a/o
745 ^a	0.982	7.44	5.45	595 ^a	1.152	1.90	1.37
729.3 ^b	0.998	6.16	4.49	575 ^a	1.179	1.48	1.07
727.5 ^b	0.999	6.67	4.87	570.2 ^b	1.186	1.35	0.971
711.3 ^b	1.016	5.23	3.81	558 ^a	1.203	1.22	0.88
700 ^a	1.028	5.41	3.94	554.5 ^b	1.208	1.14	0.817
676.5 ^b	1.053	3.77	2.73	550 ^a	1.215	1.07	0.770
676 ^a	1.054	4.48	3.25	524.5 ^b	1.254	0.505	0.362
672.5 ^b	1.057	3.84	2.78	599.8 ^b	1.294	0.242	0.173
657 ^a	1.075	3.35	2.42	477.5 ^b	1.332	0.124	0.0890
654.5 ^b	1.078	3.04	2.19	447.3 ^b	1.388	0.00479	0.0343
628 ^a	1.110	2.36	1.70	430.9 ^b	1.420	0.0285	0.0204
624.7 ^b	1.114	2.42	1.75	426.1 ^b	1.430	0.0277	0.0198
598.0 ^b	1.148	1.71	1.23	419.5 ^b	1.444	0.021-	0.015

^aJ. B. Knighton, L. Burris, Jr., and H. M. Feder.⁷³ ^bA. E. Martin and C. Wach.⁹⁴

TABLE LXXXIX. Solubility of Zirconium
in Liquid Zinc: Calculated^a

t, °C	1000 T, °K	Zirconium, w/o	Zirconium, a/o
750	0.977	7.54	5.50
725	1.002	6.16	4.49
700	1.028	4.98	3.62
675	1.055	3.99	2.89
650	1.083	3.15	2.28
625	1.113	2.46	1.78
600	1.145	1.89	1.36
575	1.179	1.43	1.031
500	1.215	0.002	0.712
525	1.253	0.518	0.371
500	1.293	0.259	0.186
475	1.337	0.1238	0.0887
450	1.383	0.0562	0.0402
425	1.432	0.0241	0.0172

^aCalculated from empirical equations.

ACKNOWLEDGMENT

The authors wish to thank R. Beck for his assistance in the analysis of the data for this report and to thank the many members of the Chemical Engineering Division who have provided unpublished solubility data for our use. Finally, we wish to acknowledge the encouragement of Dr. S. Lawroski.

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